

SOUTHWEST FISHERIES CENTER ADMINISTRATIVE

REPORTS, 1983

No. H-83-12 to H-83-20

2. INTRODUCTION

In the search for reasonable alternative policy measures, which recognize the value of coastal resource management (NRC), and the alternative technology, has resulted in the use of artificial structures. This technology has been used in various ways in the world's large water bodies and the small estuaries. It is the focus of this report.

In the early part of 1980, the National Marine and Fisheries Service (NMFS) initiated a study of the effects of artificial structures on the environment.

SUMMARY OF PERTINENT INFORMATION ON THE ATTRACTIVE EFFECTS OF ARTIFICIAL STRUCTURES IN TROPICAL AND SUBTROPICAL WATERS

The purpose of this report is to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters.

The program was formally established when NMFS issued the environmental regulations for licensing commercial FISH plants in July 1981 (Federal Register 1981/2). The regulations were primarily directed at the existing regulatory framework, with the Trade Water Act, the Fish and Wildlife Conservation Act, the Endangered Species Act, and the Fish and Wildlife Conservation Act.

In accordance with the regulations, the program was designed to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters. The program was designed to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters.

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The research plan identified the effects of artificial structures on the environment. The plan was designed to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters. The plan was designed to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters.

These structures and facilities are in the presence of an FISH plant with the design dependent upon the plant's structural design. The program FISH plant design was then classified into two general categories: structures and facilities and land-based facilities.

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In the early 1980s, land-based facilities include plant systems that are designed to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters. The plan was designed to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters. The plan was designed to provide a summary of the information available on the attractive effects of artificial structures in tropical and subtropical waters.

August 1983

REPORT OF THE COMMISSIONER OF THE GENERAL LAND OFFICE
FOR THE YEAR 1881

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I. INTRODUCTION

In the search for renewable alternate energy sources, solar seapower or ocean thermal energy conversion (OTEC), as an alternate technology, has emerged as one of the promising options. This technology would utilize a resource that is the world's largest solar collector and one which comprises 70% of the Earth's surface--the sea.

In the OTEC Act of 1980, the National Oceanic and Atmospheric Administration (NOAA) was mandated the responsibility for the establishment of a program which would help foster the development of OTEC as a commercial energy technology. In the process, provisions for the protection of the marine environments at the potential OTEC sites and considerations in minimizing adverse impacts on other users of the ocean must be emphasized.

The program was formally established when NOAA issued the environmental regulations for licensing commercial OTEC plants in July 1981 (Federal Register 1981). The regulations rely predominantly on the existing regulatory framework, such as the Clean Water Act, the Clean Air Act, the Endangered Species Act, and the Fish and Wildlife Coordination Act.

In accordance with the regulations, NOAA prepared an environmental impact statement which expressed the need for further investigation into the uncertainties of environmental effects (NOAA 1981), culminating in an environmental effects research plan (NOAA 1982).

The research plan identified two areas of research that are critical to NOAA's immediate responsibilities: the direct licensing requirements and the effects upon fisheries. This report summarizes the pertinent information of the effects upon fisheries--those of biota attraction and avoidance due to the presence of the OTEC plants.

Biota attraction and avoidance due to the presence of an OTEC plant will be highly dependent upon the plant's structural design. The proposed OTEC plant designs have been classified into two general categories: oceanic plant ships and land-based facilities.

The oceanic plant ships could be free-floating or moving slowly under their own power as they follow optimum thermal gradient conditions. Included among these designs are the experimental OTEC plant ships, "Mini-OTEC" and "OTEC-1," which were moored off Keahole Point, Hawaii (Figure 1). These plant ships are anticipated to exhibit the attractive properties characteristic of flotsam and fish aggregating devices (FAD's) employed throughout the Pacific.

As the name implies, land-based facilities include plant designs that are land-based or shelf-mounted such as man-made islands and towers (Figure 2) and would serve as artificial reefs. The towers in particular should exhibit attractive properties very similar to those of offshore drilling platforms in the Gulf of Mexico where the structures have proved instrumental in the development of a recreational fishery. It appears that

whatever OTEC plant design is used, attraction of marine organisms to the structures would be inevitable. As indicated by Yuen (1981), long-term effects on the local population in the environment will depend upon the types, sizes, and numbers of organisms attracted to the structure. There may also be possible effects on populations such as interference with or modification of breeding habits or migration routes. Some potential environmental impacts and mitigating measures related to biota attraction and avoidance are presented in Table 1.

In addition, Sullivan et al. (1981) also speculated that the increased population near the plant would compound environmental impacts, increase the difficulty of monitoring environmental effects resulting from plant operation, and potentially increase the risk of diver-related accidents due to the attraction of sharks.

II. ATTRACTION OF MARINE ORGANISMS

A. Open Ocean Plant Ships

1. Observations of attraction to floating objects

As previously mentioned, an oceanic plant ship is anticipated to exhibit attractive properties characteristic of flotsam. Many pelagic fish species have long been known to aggregate around natural and man-made objects and structures in the sea. This phenomenon is evident for all objects and structures occupying the water column and thus has provided potentially good fishing areas for sport and commercial fishermen. Throughout the Pacific, an understanding of fish aggregation has proved instrumental in the development of the pelagic fishery around FAD's and in the evolution of the man-made FAD's.

The attraction of fishes to free-floating and anchored objects or structures has been studied throughout the world's tropical and subtropical waters. The objects to which fishes have been observed to associate with include drifting seaweed (Senta 1966), driftwood (Yabe and Mori 1950; Inoue et al. 1963; Hunter and Mitchell 1967; Inoue et al. 1968), man-made rafts (Kojima 1960; Gooding and Magnuson 1967), and artificial surface or midwater structures, including the commercial FAD's (Hunter and Mitchell 1968; Klima and Wickham 1971; Wickham et al. 1973; Wickham and Russell 1974; Matsumoto et al. 1981).

Behavioral observations of fish fauna around flotsam by Hunter (1968) revealed that all species and all individuals, large or small, aggregated near the object in the presence of a fright stimulus. In addition, fishes appeared to prefer the object of their original association (also observed by Hunter and Mitchell (1967)). This was evident when in his studies, Hunter attached a second object to an object which had an existing population, and separated the two objects after a 24-hour waiting period. The result was a continued association with the original object, unless the object was completely removed from the water. Fishes were also found to be attracted to anything that drifted, and on occasion in addition to the numerous resident juveniles, schools of transient species were also observed to aggregate. As time progressed, larger fishes appeared to

dominate the flotsam population, although occasional transient schools sometimes mixed with the resident population of juveniles.

Other investigators have made various observations on fish populations around flotsam. Hunter and Mitchell (1967) found that the coloration of fishes was related to their association behavior. The darker colored species were found to remain closer to the floating object than the lighter, silvery fishes. Wickham et al. (1973) provided evidence that the distance offshore or the depth of the structures may have affected the species and number of fishes attracted and caught.

2. Theories associated with flotsam attraction

Whereas fish attraction to flotsam is well documented, theories as to why they are attracted to flotsam are still speculative. Several hypotheses have been proposed. Gooding and Magnuson (1967) suggested that floating objects served as cleaning stations where external parasites of pelagic fishes were removed by other fishes. It has been suggested that flotsam provides shade for fishes (Suyehiro 1952), produces shadows to make zooplankton more visible for fishes to feed upon (Damant 1921), and serves as a substrate for fishes to lay their eggs (Besednov 1960). Other hypotheses have suggested that fishes are attracted to flotsam because the drifting objects functioned as schooling companions (Hunter and Mitchell 1967) and that floating materials provided spatial references around which fishes could orient in an otherwise unstructured pelagic environment (Klima and Wickham 1971). Suyehiro (1952) proposed that fishes utilize floating objects as a means of seeking shelter from predators, especially for the smaller fishes which would be more susceptible to predation. In turn, Kojima (1956) suggested that larger fishes aggregate around floating objects to prey upon the smaller fishes.

It appears that although some hypotheses are valid, no single biological association or adaptive advantage can explain the aggregation of fishes around flotsam. In a given environment the association of fishes to flotsam may be species-dependent.

3. Impact upon fisheries

Fish aggregating devices have thus become instrumental in oceanic fishery development. Although fishing around FAD's has been practiced in Japan and in the Philippines for many years, it wasn't until recently that the use of FAD's for large-scale commercial fishing was first developed in the Philippines (Chikuni 1978). Since then, 23 countries have deployed or anticipate deployment of FAD's to assist the local artisanal fisheries as well as the commercial fisheries (Figure 3; Shomura and Matsumoto 1982).

Not all of the FAD's being utilized in the various areas are of the same design. Table 2 summarizes the various types, number, and longevity of the FAD's presently being used and those planned for future deployment. The early FAD's were simple bamboo rafts (not necessarily equipped with suspended midwater attractants) anchored in more protected water. The use of FAD's then extended into deeper waters and eventually to the open ocean where adverse conditions demanded sturdier construction. Developmental

studies to achieve this at the National Marine Fisheries Service, Southwest Fisheries Center Honolulu Laboratory (HL) produced a buoy-type FAD utilizing two 55-gallon steel drums. Later improvements to this model resulted in the substitution of a raft in place of the 55-gallon drums (Figure 4; Matsumoto et al. 1981). The success of the HL's designs prompted the Hawaii Department of Land and Natural Resources (DLNR) to initiate a full-scale FAD system. Initially, the DLNR's 26 FAD's were constructed of large tractor tires filled with polyurethane. This design has since undergone modifications to a pentasphere design and presently, a single sphere design (Figure 5; [Hawaii.] DLNR 1983). Other Pacific countries have since implemented their own FAD system utilizing the DLNR design, the HL design, or one of their own.

4. Organisms attracted to flotsam

From the studies by Gooding and Magnuson (1967), Hunter and Mitchell (1967), and Matsumoto et al. (1981), it seems apparent that the dominant species of fishes which are attracted to structured flotsam are pelagic or nondemersal. A list of the animals observed by Gooding and Magnuson (1967) from the observation chamber of a drifting raft serves as an index to the general nektonic faunal composition at a floating structure (Table 3). A broad classification of the behavior category (resident, visitor, and transient) of the animals in relation to the raft is also presented in the table. By definition, the transients were animals that did not appear to react to the raft but were briefly visible as they swam by; the visitors would remain near the raft for several minutes to an hour but did not aggregate; and the residents aggregated and formed an association with the raft. Some commercial species which were considered resident such as mahimahi, Coryphaena hippurus, bigeye trevally, Caranx sexfasciatus, and kahala, Seriola dumerili, were observed and captured in 2 days of fishing at the experimental plant ship, "Mini-OTEC" (once labeled the "world's largest fish aggregation buoy") (Field 1979), off Keahole Point (Johnston and Hicks 1979).

Target species for the various fisheries which capitalize on the presence of the buoys are similar. Tunas dominate the catch of the pole-and-line, trolling, handline, and purse seine boats fishing around FAD's, as evidenced by some catch data obtained from Kiribati, Western Samoa, Fiji, and Hawaii (Shomura and Matsumoto 1982). The experimental study by Matsumoto et al. (1981) provided the most detailed records of catches around FAD's in the Pacific. Table 4 presents the 1978 catch of the commercial pole-and-line boats around the Hawaiian FAD's and Table 5 presents the catch of trolling boats around the FAD's from May 1977 through July 1979. Matsumoto reported that skipjack tuna, Katsuwonus pelamis, which represented nearly 90% of the catch, dominated the catch by the pole-and-line boats. These fish ranged from 0.9 to 5.4 kg and sometimes over 9.1 kg. Unlike pole-and-line boats, trolling boats had a much more diversified catch. Tunas (mostly yellowfin tuna, Thunnus albacares, and skipjack tuna) still dominated the catch although mahimahi constituted the largest percentage of single species caught.

Another tuna fishery which utilizes FAD's (in conjunction with an artificial light source) in Hawaii is the ika-shibi or the night handline

fishery for tuna. Although this rapidly growing fishery utilizes extremely simple gear (a single hook and a line) as compared with the longliners and large purse seiners, it is an extremely effective method as indicated by the mean catch rate of approximately two fish per hook per night (Yuen 1979). From 1973 to 1975, the catch and value of tuna has shown a consistent growth from 89,000 kg, valued at \$131,000, in 1973 to 155,000 kg, valued at \$328,000, in 1975 (Table 6).

B. Land-Based Facilities

1. Platforms and artificial reefs

The land-based tower and man-made island designs of OTEC pilot plants are expected to function as artificial reefs. Stone (1974) defined artificial reefs as "...man-made or natural objects intentionally placed in selected areas of the environment to duplicate those conditions that cause concentrations of fishes and invertebrates on natural reefs and rough bottom areas." As stated by Dugas et al. (1979), because offshore oil drilling platforms are constructed solely for oil and gas production, they may not fit Stone's definition of an artificial reef; however, the platforms do function as artificial reefs and the structures produced a new marine ecosystem that was instrumental in the development of an offshore sport fishery. The attractive effects of a tower OTEC facility would appear to mirror those of an offshore drilling rig. For this summary, therefore, offshore platforms and artificial reefs will be treated together and will be referred to generally as structures.

2. Theories associated with artificial reefs

The attraction of fishes to artificial reefs may be attributed to many of the same reasons given for their attraction to floating objects, including orientation, food, shelter, and energy conservation (Stone 1978). The theory that fishes aggregate as a means of energy conservation was advanced by Stone et al. (1974) in Florida. It appeared that fishes used protected or favorable areas created by the presence of a structure which in turn dampened or deflected the strong Gulf Stream. When the current was strong, the fishes crowded inside the sheltered area whereas they scattered around or above it when the current was weak.

Depending on the structural design, attraction hypotheses such as providing shade for fishes (Suyehiro 1952), producing shadows to make zooplankton more visible for fishes to feed upon (Damant 1921), providing a substrate for fishes to lay their eggs (Besednov 1960), providing spatial references around which fishes could orient in an otherwise unstructured environment (Klima and Wickham 1971), and seeking shelter from predators (Suyehiro 1952) would appear to be valid. However, a combination of the various hypotheses would still be required to explain why such structures are attractive, thus indicating that the reasons may be species specific.

Unlike flotsam, artificial reefs are known to be prolific producers of food at the lower trophic levels. Algae, the basis of ocean life, thrive offshore on hard surfaces such as rock or concrete, provided

sufficient light is present. Consequently, algal growth is most prolific near the surface. Although the proposed structure would occupy the full water column, algal growth would be limited to the areas of the structure within the euphotic zone. As reported by Gunter and Geyer (1955), various encrusting and serpulid worms were among the organisms that took advantage of the artificial habitat created by an oil platform. A detailed description of the fauna at an artificial reef in Santa Monica Bay, California is given by Turner et al. (1969). The artificial reefs were constructed of quarry rock, concrete shelters, automobile bodies, and a streetcar. Table 7 presents the invertebrate fauna of the concrete shelter portions of the reef.

Although attraction of fish to man-made structures is well documented, questions still arise regarding the relationship between artificial structures and fish production. Mallory (1965) believed that a structure concentrated the fishes which constantly migrated in and out, thus serving as an orientation point. This was true for a number of species (primarily the game fishes) associated with flotsam. Stroud (1965) felt that since the artificial habitat provides food and shelter, reproduction will be enhanced resulting in an increase in production and yield of fishes. A third hypothesis discussed by Carlisle et al. (1964), Turner et al. (1969), and Dugas et al. (1979), combines both viewpoints: fishes are concentrated by recruitment, and, as the colonization progresses on the structures, a reproducing resident fish community may evolve. Although this may hold true for many of the reef fishes, this hypothesis falls short of accounting for overall fish attraction as evidenced primarily for such species as the deeper water pelagic scombrids and billfishes.

3. Artificial reefs and fisheries

The knowledge that artificial structures can turn barren, nonproductive areas into productive fishing habitats has been applied all over the world. The most advanced artificial reef program is in Japan, where various structural designs have been used to enhance the Japanese fishing grounds for more than 200 years (Sheehy 1981). The early artificial structures were deployed by individual fishermen using stone, wood, and scrap boats. Since then, artificial reef programs have expanded and the Japanese Government has supported programs for the past 50 years.

In 1976, the Japanese Government began its current billion dollar reef program. In essence, the structures deployed in this program are of two categories: the low-profiled tsukiiso in shallow waters and the high-profiled gyosho in deeper waters (Unger 1966; Sheehy 1981; Ogawa 1982).

The tsukiiso, meaning "bank building" or "constructed beach," is designed with the intent to improve the nearshore bottom conditions for such invertebrates as abalone, lobster, sea urchin, sea cucumber, and seaweed. Examples of these structures are shown in Figure 6.

The gyosho or "fish reef" is designed to expand natural reefs. These not only include the bottom structures but also moored midwater attractants and surface FAD's. Figure 7 presents some variations of the

gyosho. Some of the Japanese designs have since been deployed in United States' waters where, although it was evident that the prefabricated reefs were not "tailormade" for North American fisheries, they could be modified. As indicated by Sheehy (1982), the concepts developed for the units may be applied to the improvement efforts in scrap-material reefs, especially the continued use of tires, concrete rubble, ships, and offshore drilling platforms.

The Japanese programs have shown that seaweeds grow well on small, low objects; invertebrates are best attracted to structures with many holes or crevices; and the higher and larger the structure, the more fishes are attracted to it (Unger 1966; Sheehy 1981).

4. Organisms attracted to artificial reefs

Numerous studies have described the variety of fishes which have been attracted to artificial reefs at various sites. In all studies, the many different species found generally represent similar basic broad behavioral classes (such as the Turner et al. (1969) reef or nonreef associations; the former further split into resident or semiresident). Presented in Table 8 is a list of fishes observed at an artificial reef project in Hawaii, which is in close proximity to a proposed OTEC site.

Four reefs were established at various sites in Hawaii between 1960 and 1973, using primarily car bodies, damaged concrete pipes, and old car tires filled with mortar. The southern boundary of a reef created at one of these sites (Waianae) on the western coast of the Island of Oahu is at lat. 21°25.1'N, long. 158°11.6'W (Kanayama and Onizuka 1973). This site is only 3 miles from the present OTEC benchmark survey site at lat. 21°19.5'N, long. 158°12.5'W (Figure 8; Jones 1981).

In the study at the Waianae artificial reef, sampling along a fish transect established before the reef construction indicated the presence of 32 different species and a standing crop density of 103 pounds of fish per acre. Kanayama and Onizuka (1973) used the change in the density between the pre- and post-reef construction transects as an index to rate the reef's effectiveness in increasing fish life. The reef was constructed in two sections, one composed of car bodies and the other of damaged concrete pipes. Thirty species of fishes (standing crop estimated at 1,271 pounds per acre) were present at the car body section. This was a tenfold increase over the pre-reef count. The concrete pipe section showed a fivefold increase of 45 fish species and a standing crop estimated at 496 pounds per acre. The results of the surveys conducted at the Waianae reef as well as at three other sites are presented in Table 9.

Since offshore platforms occupy the entire water column, they have additional attraction potentials. Epipelagic fish species which occupy the water column near commercial FAD's have been observed at platforms. The fish fauna at an offshore platform and the use of the water column near the structure as a habitat were discussed by Hastings et al. (1976), in their study of two offshore platforms (one 32 m deep and the other 18 m deep) in the northeastern Gulf of Mexico (Table 10).

In addition, Dugas et al. (1979) summarized the major game fish species which were attracted to and caught at platforms in the Gulf of Mexico off the Louisiana coast (Table 11). It was emphasized that the proliferation of offshore oil and gas platforms has contributed immensely to the development of the state's offshore sport fishery.

C. Attraction to Night Illumination

The attraction of various marine organisms to light is a phenomenon that has been used in the harvesting of fish for many years. Mackerel scad, Decapterus macarellus, and bigeye scad, Selar crumenophthalmus (Yamaguchi 1953; Powell 1968), various species of tuna (Yuen 1979), and squid (Ogura and Nasumi 1976), are caught by the use of night lights. As indicated by Sullivan et al. (1981) and Yuen (1981), the impact upon both planktonic and nektonic organisms attracted to light from an OTEC facility is a major concern.

In the recent survey of the fishery resources in the Northwestern Hawaiian Islands conducted by the HL, night-light fishing was used as one of the sampling methods. The light (a 1,500-W bulb) was initially submersed to 21.3 m (the maximum amount of wire out). After an hour, the light would be raised to about 10 m below the surface and to within 2 m about an hour after that. The purpose for the lowering and raising was to attract the organisms farther down and draw them to the surface with the light. The intensity of the light was controlled with a rheostat. Dimming the light concentrated the organisms and facilitated observation and collection.

Generally, the first organisms to appear around the light were zooplankton. This was also observed by Powell (1968). Soon after the zooplankton have collected within the radius of the light, larger organisms appear.

Among the positively phototactic species are the baitfish, such as the silversides (Atherinidae) and small round herrings (Clupeidae). Flyingfishes (Exocoetidae), halfbeaks (Hemiramphidae), filefishes (Monacanthidae), and lanternfishes (Myctophidae) are also commonly seen around night lights.

In addition to the mackerel scad, bigeye scad, squids, and tunas, other marketable fishes taken at the night light were the squirrelfishes, Myripristis spp., and the red bigeyes, Priacanthus spp.

How much an effect the lights from an OTEC facility will have on the fauna is not presently known. As indicated by Laevastu and Hayes (1981), every species has a particular optimum light intensity in which its activity is at a maximum. It is probable that the lux of the artificial lights would fall within the thresholds of some species.

D. Seasonal and Diurnal Variations

The fish community attracted to artificial structures varies with the season. In a study of two platforms off the Florida Gulf coast,

differences in faunal composition with seasonal changes were obvious. Hastings et al. (1976) found that changes in fish fauna were correlated with temperature and that larger numbers of species were present during the warmer months of summer and fall, whereas the least were observed through the winter and spring. The seasonal estimates of abundance (Table 10) indicated that most species leave the area in the winter and gradually return in the spring or summer.

Among the fishes which may exhibit seasonal variation and those most apt to be affected by the presence of offshore structures are the game fishes. These include the billfishes, mahimahi, and tunas.

The occurrence of adult male blue marlin, Makaira nigricans, appears to be seasonal throughout its range (Rivas 1975). In Hawaii, blue marlin catches are highest in summer and lowest in winter. Similarly, the largest catches in Puerto Rico are made in August, September, and October, and the lowest in December. In their study of billfish caught by longline in the eastern Pacific, Kume and Joseph (1969) suggested that blue marlin segregated into distinct areal groups according to sex.

In Hawaii, striped marlin, Tetrapterus audax, occurs from fall through spring and is abundant mainly in the summer months, in complement to the blue marlin (Strasburg 1970). The distribution of the striped marlin in its range throughout the rest of the world is also seasonal (Ueyanagi and Wares 1975).

The abundance of mahimahi is seasonal throughout its range although the season of peak abundance varies greatly (Palko et al. 1982). It was also reported that because many environmental factors are interlinked and dependent upon the prevailing oceanographic conditions, it was probable that the various factors contributed in varying degrees to the seasonal abundance of the species.

The two major commercial tunas in Hawaii, the skipjack and yellowfin, are usually available during the entire year although a marked increase is evident during the warmer months of May to September (Schaefer et al. 1963; Waldron 1963). Most if not all of the other game fishes in the world also exhibit seasonal variation. Generally, oceanographic (temperature and salinity) and environmental influences determine all the seasonal distributions of the species.

Although numerous marine organisms exhibit diel vertical migrations, the largest community, the vertically migrating deep scattering layer is too deep to pose a realistic attraction problem. The migratory behavior is influenced by the occurrence of natural light (Boden and Kampa 1967) but no evidence exists that the community responds to any attractive effect posed by a structure or artificial light source.

III. AVOIDANCE OF STRUCTURES BY MARINE ORGANISMS

Among the major concerns regarding the presence of an OTEC facility is the impact upon the marine species that are classified as being endangered or threatened. At the present time, not much is known about attraction or

avoidance responses of these animals to the facilities; therefore, impact assessments have been mainly speculative. Yuen (1981) indicated that the endangered and threatened species would probably avoid the area due to human presence and to the noise emitted from the plant. Sullivan et al. (1981) presented a list of these species and their distribution at the candidate OTEC sites (Table 12).

Research on fishing gear and methods in the past have concentrated on developing fishing techniques which utilize the understanding of fish behavior to achieve better catches per unit of effort. Thus, emphasis has been placed on attraction rather than avoidance of organisms. Among the few studies that address avoidance was one on the negative phototactic behavior of fish. Dragesund (1958) found that herring would sometimes display a shock response. That is, when the light was turned on, the fish would make a sudden upward movement towards the light only to later disperse or school and descend.

Studies on other aspects of avoidance, such as of the physical structures, are nonexistent in published literature. Future studies should be directed in this area.

IV. SUMMARY AND CONCLUSIONS

The environmental considerations for deployment of an OTEC facility would depend to a large extent upon the benefits and adverse effects produced by the attraction of marine organisms to such a structure. As stated by Sullivan et al. (1981), "...because of the synergistic effect attraction has on impacts, attraction is the most important environmental effect associated with platform deployment."

The obvious benefit from the construction of an OTEC facility is the possibility for fishery enhancement. If the results obtained by the use of FAD's and offshore platforms are any indication of what could be expected by the presence of an OTEC facility, commercial and recreational fishermen would benefit greatly by its deployment. It would be a further plus if the artificial reef created by the facility not only aggregate organisms but serves as the substrate and habitat to enhance the production of the marine community.

Along with the benefits to fishery development are man-made disturbances to the environment. Combined with the noise from the plant, the increased activity and presence of man may affect the larger marine animals (in particular the endangered and the threatened species) from the area. In recent years, these animals have become the subject of much public concern and thus, any OTEC deployment must seriously consider any potential impacts upon them.

Much research is still needed in the study of the attraction and avoidance effects upon marine organisms because of the alteration of their natural environment. The effects of other possible nonstructural attractants, such nutrients which are added to the environment by a coexisting aquaculture farm or chlorine or other biocides discharged from the facility, have not been tested. Research is continuing on the

possible use of cold water effluent from a coexisting OTEC plant by the Natural Energy Laboratory of Hawaii aquaculture farm. Thus, the study of the attraction effects of the farm's nutrient-rich effluent may be advised. Practically no information is presently available on the avoidance by marine organisms of artificial changes in the environment.

It is evident from what is known about attraction, that the design and location of structures will prove extremely important with respect to the severity of any environmental impact.

V. LITERATURE CITED

Besednov, L. N.

1960. Some data on the ichthyofauna of Pacific Ocean flotsam. [In Russ.] Tr. Inst. Okeanol. Acad. NAUK SSSR 41:192-197. (Engl. transl. by W. G. Van Campen, 1963, 7 p.; Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.)

Boden, B. P., and E. M. Kampa.

1967. The influence of natural light on the vertical migrations of an animal community in the sea. Symp. Zool. Soc. Lond. 19:15-26.

Carlisle, J. G., C. H. Turner, and E. E. Ebert.

1964. Artificial habitat in the marine environment. Calif. Dep. Fish Game, Fish Bull. 124, 113 p.

Chikuni, S.

1978. Report on fishing for tuna in Philippine waters by FAO-chartered purse seiners. Part I. Exploratory fishing and biological features of resources. United Nations Dev. Program, South China Sea Fish. Dev. Coord. Program, SCS/78/WP/74:1-44.

Damant, G. C. C.

1921. Illumination of plankton. Nature (Lond.) 108:42-43.

Dragesund, O.

1958. Reactions of fish to artificial light, with special reference to large herring and spring herring in Norway. J. Cons. Cons. Int. Explor. Mer 23:213-227.

Dugas, R., V. Guillory, and M. Fischer.

1979. Oil rigs and offshore sport fishing in Louisiana. Fisheries 4(6):2-10.

Federal Register.

1981. Licensing of ocean thermal energy conversion facilities and plantships (as amended by 46 FR 61643 et seq., Dec. 18, 1981), 15 CFR 981. Federal Register 46(147):39388-39420.

Field, N.

1979. "Mini OTEC" could be Hawaii's largest fish aggregating device.
Hawaii Fish. News 3(9):19, June 23, 1979.

Gooding, R. M., and J. J. Magnuson.

1967. Ecological significance of a drifting object to pelagic fishes.
Pac. Sci. 21:486-497.

Gunter R., and R. A. Geyer.

1955. Studies on the fouling organisms of the northwest Gulf of Mexico. Publ. Inst. Mar. Sci. 4:37-67.

Hastings, R. W., L. H. Ogren, and M. T. Mabry.

1976. Observations on the fish fauna associated with offshore platforms in the northeastern Gulf of Mexico. Fish. Bull., U.S. 74:387-402.

[Hawaii.] Department of Land and Natural Resources.

1979. Statewide fish aggregating system project. Project report.
Hawaii Fish. News 4(6):4-5, October 27, 1979.

1983. Hawaiian fish aggregating buoys. Status report. January 1983. 13 p.

[Hawaii.] Department of Planning and Economic Development.

1980. OTEC for Oahu; a report on the development of a pilot plant for ocean thermal energy conversion at Kahe Point, Oahu, Hawaii. Ad Hoc Committee on the Advancement of OTEC for Hawaii, 37 p.

Hunter, J. R.

1968. Fishes beneath flotsam. Sea Frontiers 14:280-288.

Hunter, J. R., and C. T. Mitchell.

1967. Association of fishes with flotsam in the offshore waters of Central America. U.S. Fish Wildl. Serv., Fish. Bull. 66:13-29.

1968. Field experiments on the attraction of pelagic fish to floating objects. J. Cons. Cons. Perm. Int. Explor. Mer 31:427-434.

Inoue, M., R. Amano, and Y. Iwasaki.

1963. Studies on environments alluring skipjack and other tunas--I. On the oceanographical condition of Japan adjacent waters and the drifting substances accompanied by skipjack and other tunas. [In Jpn., Engl. summ.] Rep. Fish. Res. Lab., Tokai Univ. 1:12-23.

Inoue, M., R. Amano, Y. Iwasaki, and N. Yamauti.

1968. Studies on environments alluring skipjack and other tunas--II. On the driftwoods accompanied by skipjack and tunas. Bull. Jpn. Soc. Sci. Fish. 34:283-287.

Johnston, C., and R. Hicks.

1979. We fished the "Mini OTEC." Hawaii Fish. News 4(8):8-11.

Jones, A. T.

1981. List of fish at a proposed OTEC site off Kahe Point, Hawaii. Derived from commercial fish records, 1959-1978. Lawrence Berkeley Lab., Univ. Calif., Berkeley, Earth Sci. Div., LBL-12947, UC-64, 12 p.

Kanayama, R. K., and E. W. Onizuka.

1973. Artificial reefs in Hawaii. Hawaii Fish Game Rep. 73-01, 23 p.

Klima, E. F., and D. A. Wickham.

1971. Attraction of coastal pelagic fishes with artificial structures. Trans. Am. Fish. Soc. 100:86-99.

Kojima, S.

1956. Fishing for dolphins in the western part of the Japan Sea--II. Why do the fish take shelter under floating materials. [In Jpn., Engl. summ.] Bull. Jpn. Soc. Sci. Fish. 21:1049-1052. (Engl. transl. by W. G. Van Campen, 1962, 4 p.; Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.)

1960. Fishing for dolphins in the western part of the Japan Sea--V. Species of fishes attracted to bamboo rafts. [In Jpn., Engl. summ.] Bull. Jpn. Soc. Sci. Fish. 26:379-382. (Engl. transl. by W. G. Van Campen, 1962, 4 p.; Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.)

Kume, S., and J. Joseph.

1969. Size composition and sexual maturity of billfish caught by the Japanese longline fishery in the Pacific Ocean east of 130°W. Bull. Far Seas Fish. Res. Lab. (Shimizu) 2:115-162.

Laevastu, T., and M. L. Hayes.

1981. Fisheries oceanography and ecology. Page Bros. (Norwich) Ltd., Norwich, 199 p.

Mallory, J. D.

1965. Artificial reefs in shallow waters. Proc. Int. Game Fish Comm. 10:29-37.

Matsumoto, W. M., T. K. Kazama, and D. C. Aasted.

1981. Anchored fish aggregating devices in Hawaiian waters. Mar. Fish. Rev. 43(9):1-13.

National Oceanic and Atmospheric Administration (NOAA).

1981. Final environmental impact statement for commercial ocean thermal energy conversion (OTEC) licensing. NOAA, Office of Ocean Minerals and Energy, Wash., D.C., var. pag.

1982. Ocean thermal energy conversion: Environmental effects assessment program plan, 1981-85. NOAA, Office of Ocean Minerals and Energy, Wash. D.C., 54 p.

Ogawa, Y.

1982. Jinko gyosho, tsukiiso, and marine organisms. In Japanese artificial reef technology, p. 42-48. Translations of selected Japanese literature and an evaluation of potential applications in the U.S. Introduction and evaluation by D. J. Sheehy, translated by J. Y. Haga, and edited by S. F. Vik. Aquabio, Inc. Tech. Rep. 604:42-48.

Ogura, M., and T. Nasumi.

1976. Fishing lamps and light attraction for squid jigging. In Contributed papers submitted to the expert consultation on fishing for squid and other cephalopods. Suppl. 1, 93-96. FAO Fish. Rep. 170.

Palko, B. J., G. L. Beardsley, and W. J. Richards.

1982. Synopsis of the biological data on dolphin-fishes Coryphaena hippurus Linnaeus and Coryphaena equiselis Linnaeus. NOAA Tech. Rep. NMFS Circ. 443, 28 p. [FAO Fish. Synop. 130.]

Powell, R.

1968. "Akule" night fishing gear. South Pac. Comm., Noumea, New Caledonia, 13 p.

Rivas, L. R.

1975. Synopsis of biological data on blue marlin, Makaira nigricans Lacepede, 1802. In R. S. Shomura and F. Williams (editors), Proceedings of the International Billfish Symposium, Kailua-Kona, Hawaii, 9-12 August 1972. Part 3. Species synopses, p. 1-16. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-675.

Schaefer, M. B., G. C. Broadhead, and C. J. Orange.

1963. Synopsis on the biology of yellowfin tuna Thunnus (Neothunnus) albacares (Bonnaterre) 1788 (Pacific Ocean). FAO Fish. Rep. 6, 2:538-561.

Senta, T.

1966. Experimental studies on the significance of drifting seaweeds for juvenile fishes--I. Experiments with artificial drifting seaweeds. Bull. Jpn. Soc. Sci. Fish. 32:639-642.

Sheehy, D. J.

1981. Artificial reef programs in Japan and Taiwan. In D. Y. Aska (editor), Artificial reefs: Conference proceedings, p. 185-198. Fla. Sea Grant Coll. Rep. 41.

1982. The use of designed and prefabricated artificial reefs in the United States. Mar. Fish. Rev. 44(6-7):4-15.

Shomura, R. S., and W. M. Matsumoto.

1982. Structured flotsam as fish aggregating devices. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-22, 9 p.

Stone, R. B.

1974. A brief history of artificial reef activities in the United States. Proc. Int. Conf. Artificial Reefs, p. 24-27.

1978. Artificial reefs and fishery management. Fisheries 3(1):2-4.

Stone, R. B., C. C. Buchanan, F. W. Steimle, Jr.

1974. Scrap tires as artificial reefs. Summ. Rep. SW-119. U.S. Environmental Protection Agency.

Strasburg, D. W.

1970. A report on the billfishes of the central Pacific Ocean. Bull. Mar. Sci. 20:575-604.

Stroud, R. H.

1965. Artificial reefs as tools of sport fishery management in coastal marine waters. Proc. Int. Game Fish Comm. 10:2-12.

Sullivan, S. M., M. D. Sands, J. R. Donat, P. Jepsen, M. Smookler, and J. F. Villa.

1981. Draft environmental assessment ocean thermal energy conversion (OTEC) pilot plants. Lawrence Berkeley Lab., Univ. Calif., Berkeley, Earth Sci. Div., LBL-12328, UC-64, var. pag.

Suyehiro, Y.

1952. Textbook of ichthyology. [In Jpn.] Iwanami Shoten, Tokyo, 332 p.

Turner, C. J., E. E. Ebert, and R. R. Given.

1969. Man-made reef ecology. Calif. Dep. Fish Game, Fish Bull. 147, 221 p.

Ueyanagi, S., and P. G. Wares.

1975. Synopsis of biological data on striped marlin, Tetrapturus audax (Philippi), 1887. In R. S. Shomura and F. Williams (editors), Proceedings of the International Billfish Symposium, Kailua-Kona, Hawaii, 9-12 August 1972. Part 3. Species synopses, p. 132-159. NOAA Tech. Rep. NMFS SSRF-675.

Unger, I.

1966. Artificial reefs--a review. Am. Littoral Soc., Spec. Publ. 4, 74 p.

Waldron, K. D.

1963. Synopsis of biological data on skipjack Katsuwonus pelamis (Linnaeus) 1758 (Pacific Ocean). FAO Fish. Rep. 6, 2:695-748.

Wickham, D. A., and G. M. Russell.

1974. An evaluation of mid-water artificial structures for attracting coastal pelagic fishes. Fish. Bull., U.S. 72:181-191.

Wickham, D. A., J. W. Watson, Jr., and L. H. Ogren.

1973. The efficacy of midwater artificial structures for attracting pelagic sport fish. Trans. Am. Fish. Soc. 102:563-572.

Yabe, H., and T. Mori.

1950. An observation on the habit of bonito, Katsuwonus vagans, and yellowfin, Neothunnus macropterus, schools under the drifting timber on the surface of ocean. [In Jpn., Engl. abstr.] Bull. Jpn. Soc. Sci. Fish. 16:35-39. (Engl. transl. by W. G. Van Campen, 1954, 12 p.; Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.)

Yamaguchi, Y.

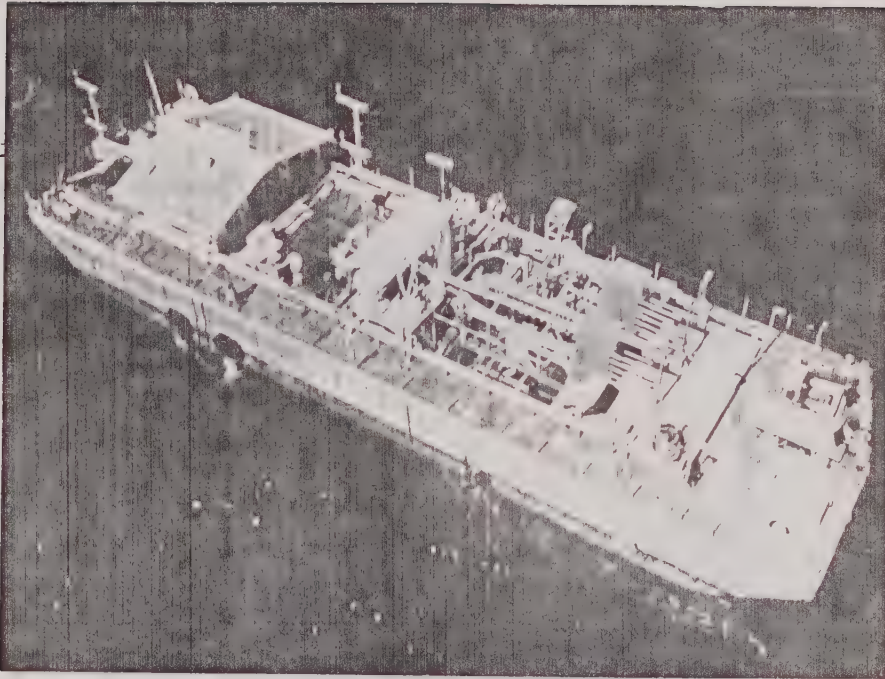
1953. The fishery and the biology of the Hawaiian opelu, Decapterus pinnulatus (Eydoux and Souleyet). M. S. Thesis, Univ. Hawaii, Honolulu, 125 p.

Yuen, H. S. H.

1979. A night handline fishery for tunas in Hawaii. Mar. Fish. Rev. 41(8):7-14.

Yuen, P. C.

1981. Ocean thermal energy conversion: A review. Hawaii Natural Energy Institute, Univ. Hawaii at Manoa, HNEI-81-03, 173 p. (Based on a paper prepared for Florida Solar Energy Center's Solar Technology Assessment, March 1981.)



(a) Mini-OTEC

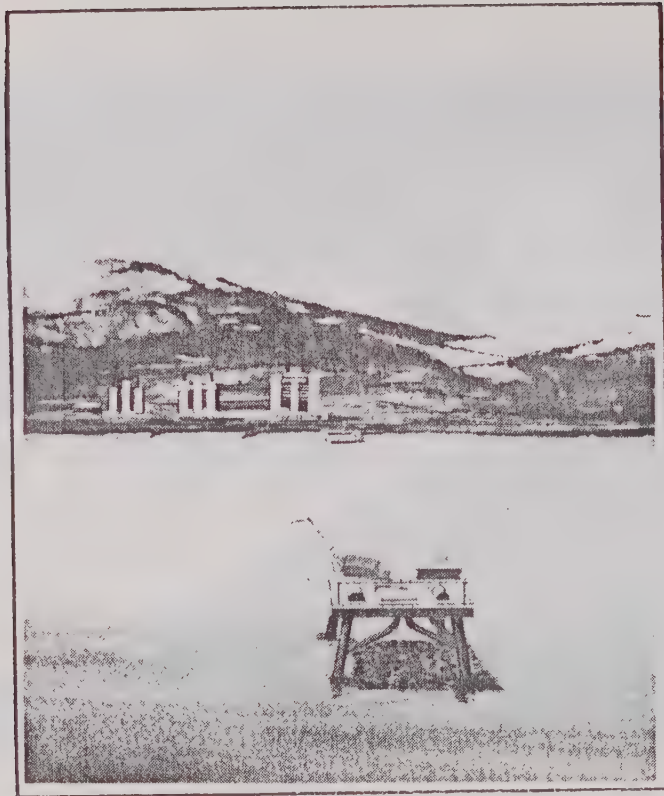
(Photo courtesy of the State of Hawaii, Department of Planning and Economic Development, Honolulu, Hawaii.)



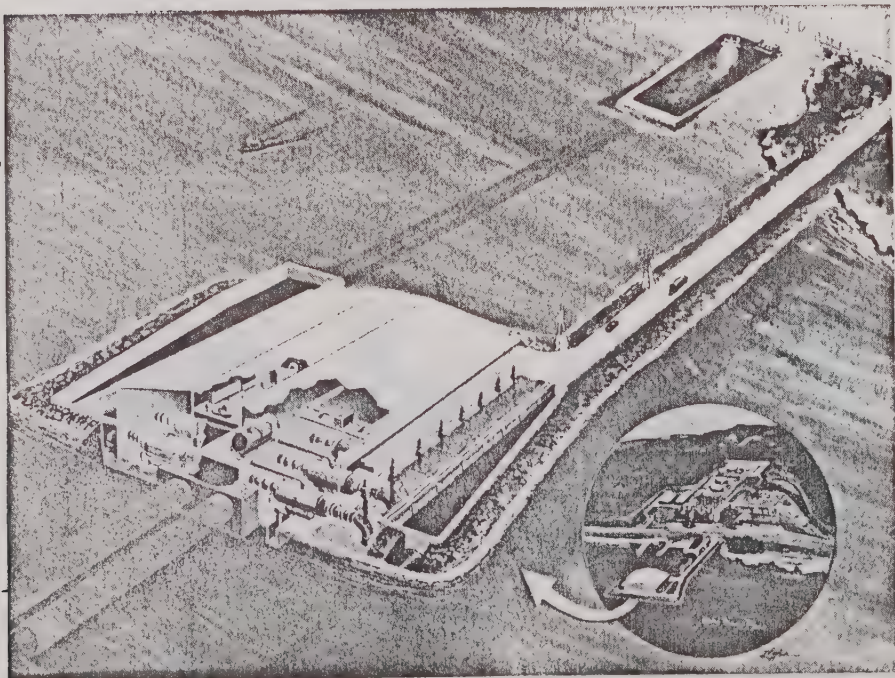
(b) OTEC-1

(Photo courtesy of J. J. Naughton, Western Pacific Program Office, National Marine Fisheries Service, NOAA, Honolulu, Hawaii.)

Figure 1.--Experimental open ocean plantships deployed off Keahole Point, Hawaii.



(a)



(b)

Figure 2.--The OTEC land based designs for Kahe Point, Hawaii.

(a) The General Electric tower concept pilot plant design.

(b) The Ocean Thermal Corporation man-made island pilot plant design.

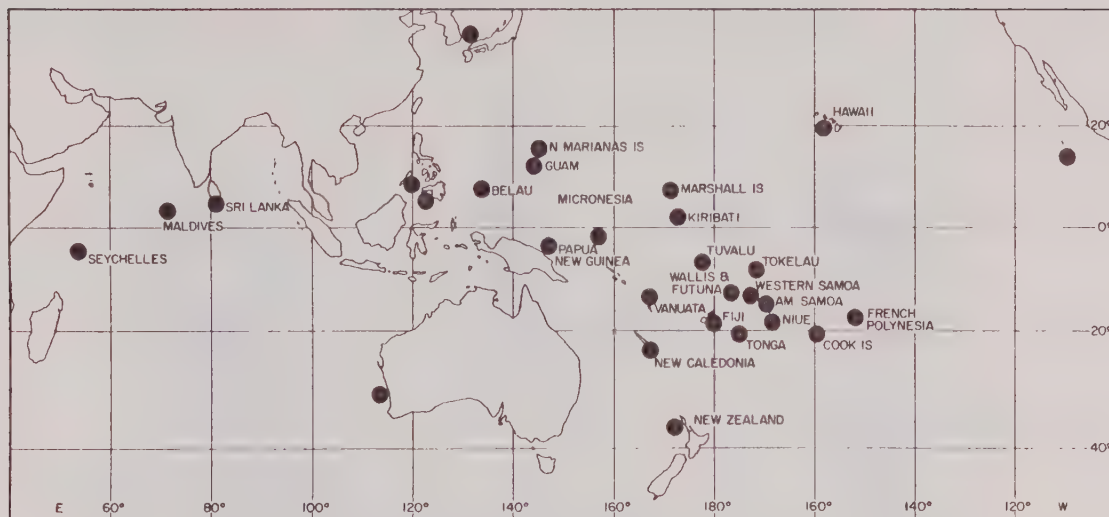


Figure 3.--Locations where fish aggregating devices have been deployed 1979-81, or where deployment is planned in the Pacific and Indian Oceans (Shomura and Matsumoto 1982).

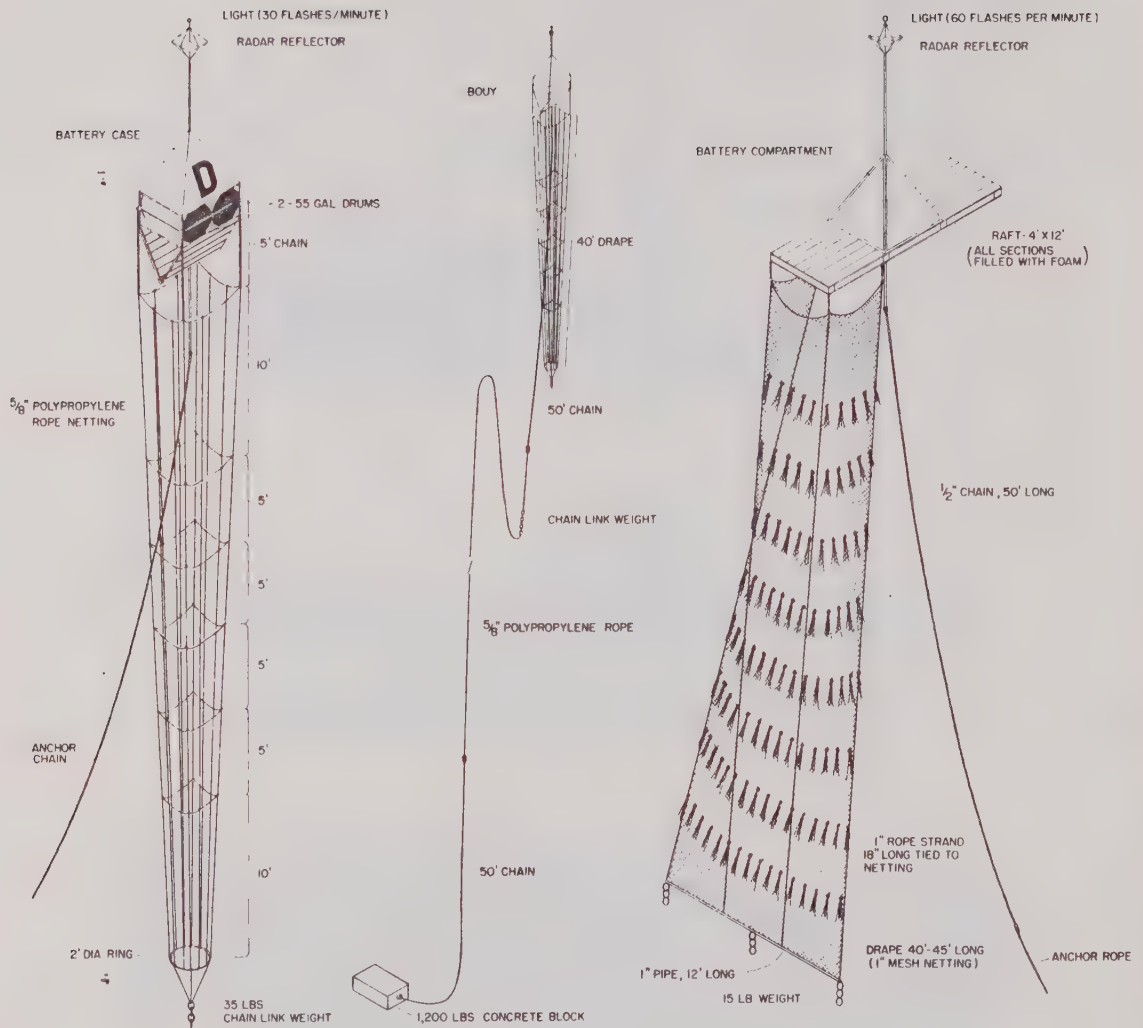


Figure 4.--Experimental designs for Honolulu Laboratory's fish aggregating devices.

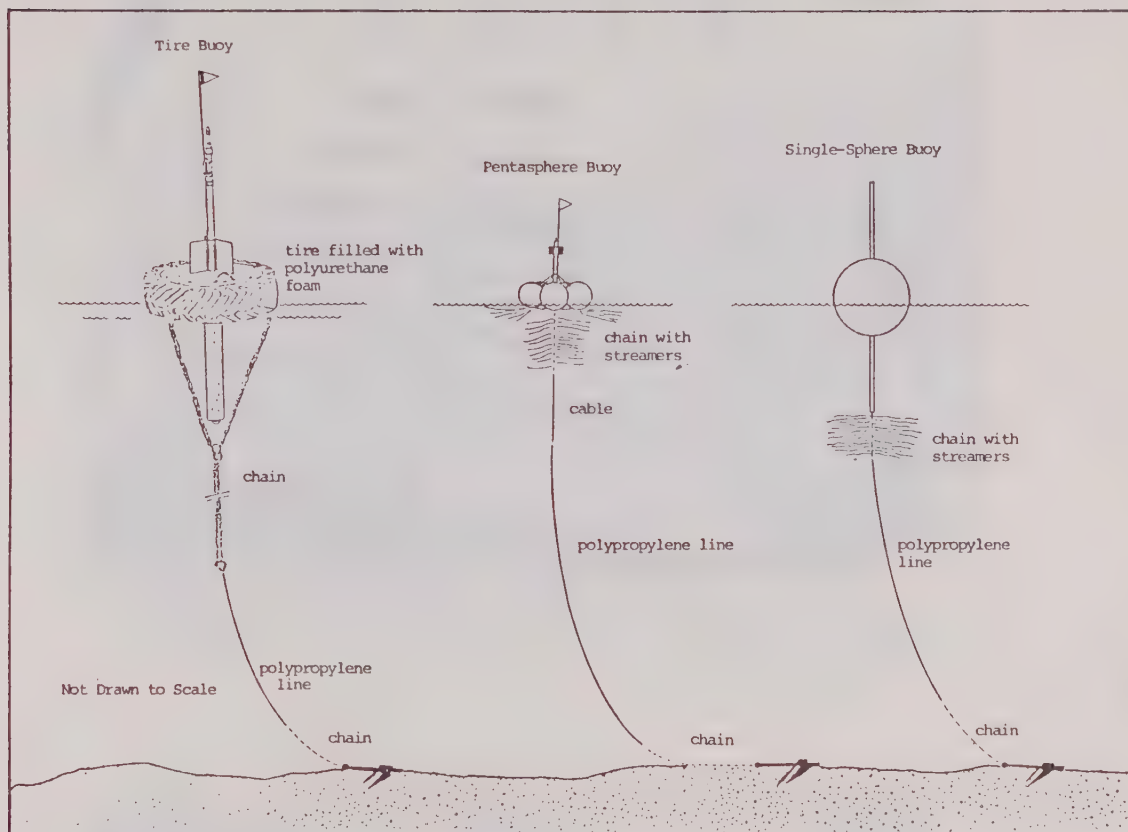
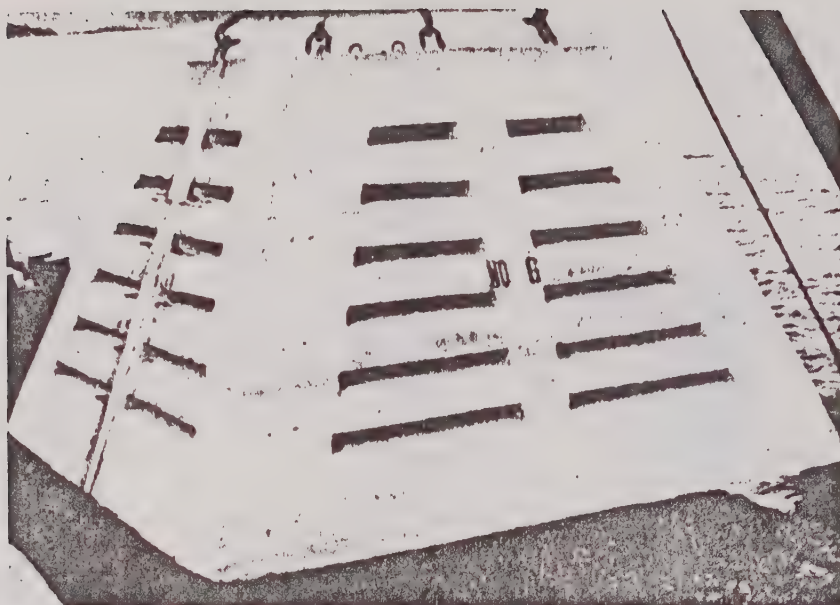


Figure 5.--Department of Land and Natural Resources' fish aggregating device designs ([Hawaii.] Department of Land and Natural Resources 1983).



Shelter unit for spiny lobster used in Nagasaki.
Photo credit: Mr. Inui.



Shelter unit for lobster in Miyazaki.
Photo credit: Mr. Uchida.

Figure 6.--Variations of the Japanese tsukiiso or constructed beach (Sheehy 1981).



Abalone shelter unit being placed in Hokkaido.
Photo credit: Dr. Sato.



Abalone shelter unit composed of FRP frame
with rocks. Asahi Chemical International, Ltd.
Photo credit: Dr. Ogawa.

Figure 6.--Continued.



Large scale prefabricated fish reef of reinforced concrete by Ishikawajima Kensai Kogyo Co., Ltd.
Photo credit: IKK Co., Ltd.

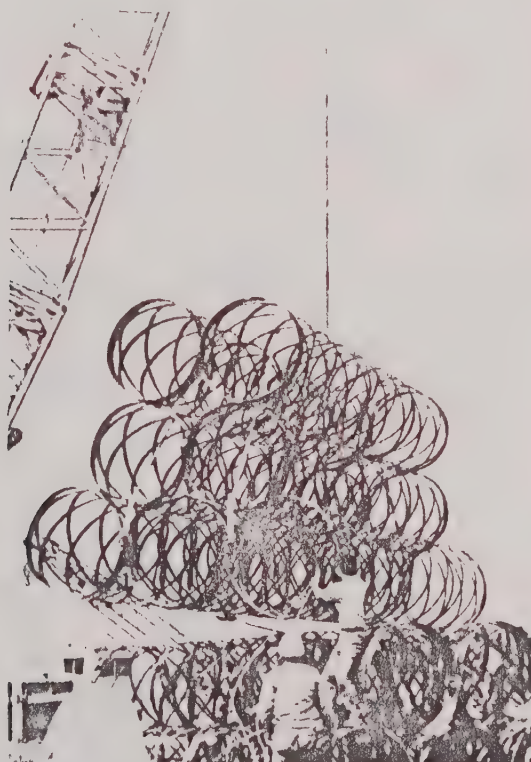


"Dragon Reef" under construction at shore staging area. Photo credit: Onoda Cement Co., Ltd.

Figure 7.--Variations of the Japanese gyosho or fish reef (Sheehy 1981).



"Kamaboko Reefs," in two different configurations.
Photo credit: Ryowa Concrete Industries, Inc.



Fiberglass reinforced plastic reefs
manufactured by Asahi Chemical Inter-
national, Ltd. Photo credit: Dr. Ogawa.

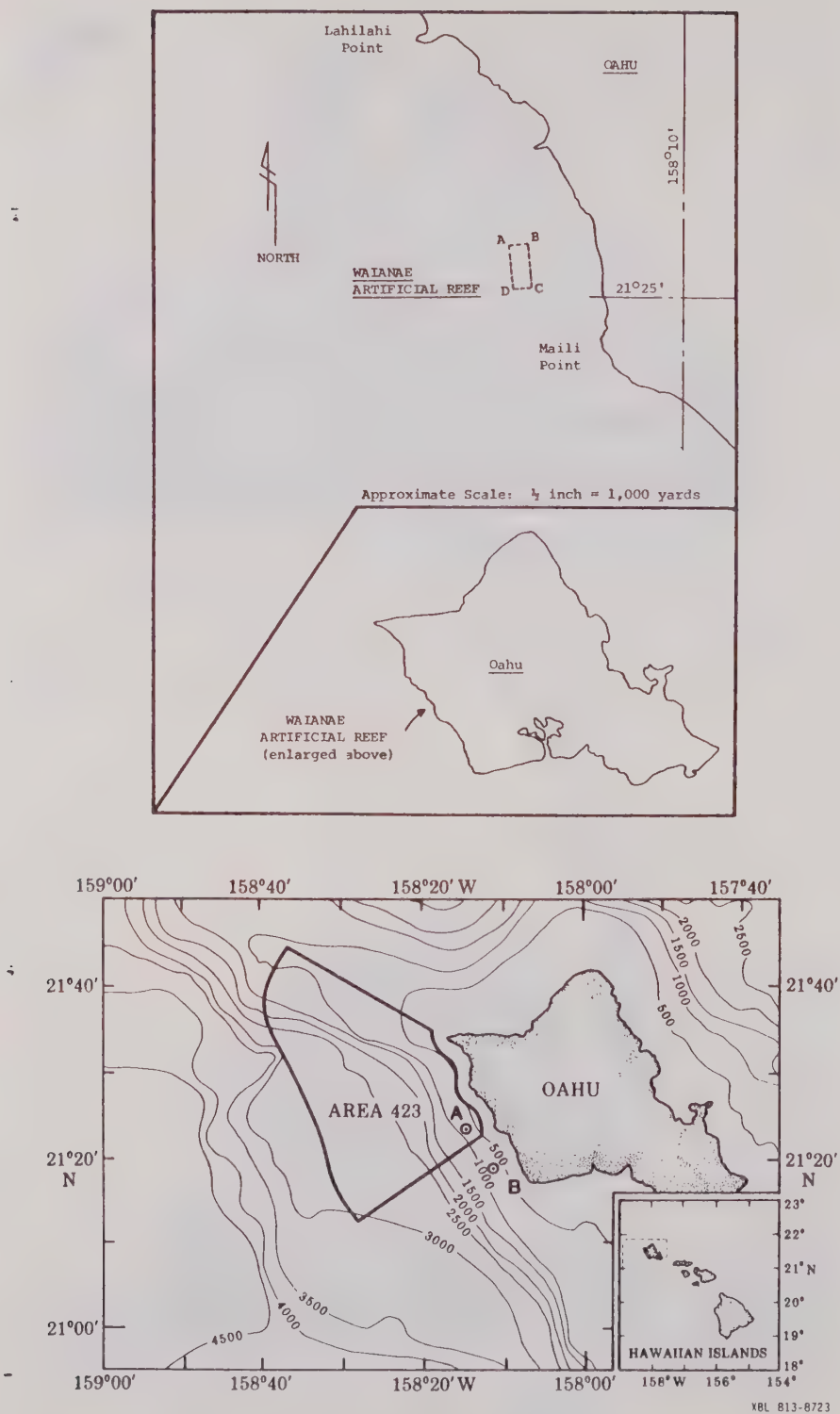


Figure 8.--The position of the Waianae artificial reef (a) (Kanayama and Onizuka 1973) and the present OTEC environmental benchmark survey (b) (Jones 1981).

TABLE 1. Potential adverse environmental impacts and mitigating measures related to biota attraction and avoidance at an ocean thermal energy conversion site (from Yuen 1981).

Issue	Community Affected					Mitigating Measures (Ranked by Effectiveness)	Research Needs
	Plankton	Nekton	Benthos	Threatened and Endangered Species	Man's Activities		
Biota Attraction and Avoidance	Increased number of organisms due to attraction to lights.	Increased number of organisms due to attraction to structure and lights.	Colonization of exposed structures.	Possible avoidance of area due to human presence and noise.	-Increased fishing. -Loss of desired faunal diversity.	-Site away from breeding and nursery grounds. -Reduce lights and noise to minimum needed for safe operation. -Reduce attraction surfaces.	-Site evaluation studies to determine ecological sensitivity of areas. -Determine biota attraction and avoidance to different platform configurations and lighting systems.

TABLE 2. Deployment and longevity of fish aggregating devices in the Pacific and Indian Oceans,¹ 1979-81 (from Shomura and Matsumoto 1982).

Country or locality	Type of fish aggregating device	No. set (planned)	No. lost	Fish aggregating device (days)			
				Range	Mean	Max.	Continuing ²
American Samoa	3-drum	11	11	7-510	266.0	510	No
	Doughnut	5 (8)	3	14-60	35.0	250	Yes
Australia	3-drum	4	4	335-427	365.5	427	No
	Foam block	2 (6)	--	--	--	120	Yes
Cook Islands	3-drum	1	1	150	--	150	No
	Aluminum catamaran	4 (2)	--	227-592	--	592	Yes
Eastern Pacific	Plyboard raft	5	5	62-137	107.3	137	No
Fiji	Bamboo raft	120	96	1 year	--	--	--
	Wooden raft	2	1	--	--	120	--
	Aluminum catamaran	1	--	--	--	--	--
French Polynesia	3-drum	8	4	--	--	--	--
Guam	3-drum	3	3	6-123	70.3	123	No
	Tractor tire	5	3	28-258	142.6	338	Yes
Hawaii	Tractor tire	26	11	60-540	237.3	540	No ³
	Pentaspere	34 (45)	25	30-450	164.4	450	No
Kiribati	Fiberglass-pole raft	3 (6)	3	7-40	25.0	40	No
Maldives Islands	Various types	9	--	--	--	--	--
Marshall Islands	Bamboo raft	(20)	--	--	--	--	--
Micronesia	--	20+	--	--	--	--	--
New Caledonia	--	(6)	--	--	--	--	--
New Zealand	--	3	--	--	--	--	--
Niue	Aluminum single hull	(2)	--	--	--	--	--
Northern Marianas	3-drum	5	5	150-310	162.0	210	No
Belau	Tractor tire	6	6	30-270	150.0	270	No
Papua New Guinea	Bamboo raft	76	25	--	--	--	--
Seychelles	Pipe-frame raft	5 (10)	1	60	--	123	Yes
Sri Lanka	--	(12)	--	--	--	--	--
Tokelau	--	(1)	--	--	--	--	--
Tonga	Aluminum catamaran	2 (2)	2	30-210	120.0	210	No
Tuvalu	--	(NA)	--	--	--	--	--
Vanuatu	Plyboard raft	(5)	--	--	--	--	--
Wallis and Futuna	--	(5)	--	--	--	--	--
Western Samoa	3-drum	5	5	236-270	257.4	270	No
	Aluminum catamaran	23 (3)	10	287-424	368.2	566	Yes
Total/range		379+ (147)	224			40-592	

¹Exclusive of countries that used FAD's prior to 1979.²Maximum FAD life continuing as of April 1982.³Maximum FAD life continuing as of June 1982. All existing tire type FAD's removed and replaced by pentaspere type.

TABLE 3. Animals seen from the observation chamber of a drifting raft*
(from Gooding and Magnuson 1967).

SPECIES, GENUS, OR FAMILY (Common Name in Parentheses)	DRIFT LOCATION	BEHAVIOR CATEGORY	FORK LENGTH (cm)	MAXIMUM NUMBER SEEN AT ONE TIME
<i>Abudefduf abdominalis</i> (damselfish)	H	R	0.7-1.0 [†]	24
<i>Acanthocybium solandri</i> (wahoo)	H03	R	45-90	3
<i>Alutera scripta</i> (scrawled filefish)	H	RV	10-35	2
<i>Canthidermis maculatus</i> (rough triggerfish)	H	R	25-35 [†]	33
<i>Caranx kalla</i> (golden jack)	H	V	30	1
<i>Caranx</i> sp. (jack)	H	R	2.9-5.3 [†]	3
<i>Carcharhinus longimanus</i> (whitetip shark)	H03	RV	125-175	2
<i>Chelonia mydas</i> (green turtle)	0	V	60	1
<i>Coryphaena equiselis</i> (pompano dolphin)	03	V	30	100+
<i>Coryphaena hippurus</i> (dolphin)	H03	R	60-100 [†]	70+
<i>Coryphaena</i> sp.	H03	R	10-15	80
<i>Decapterus pinnulatus</i> adult (mackerel scad)	H03	RT	20-25	1,000+
juvenile	3	R	13.1 [†]	1
Diodontidae (spiny puffer)	0	V	12	1
Echeneidae (free-swimming) (remora)	3	R	8	1
<i>Elagatis bipinnulatus</i> (rainbow runner)	3	R	75	1
Exocoetidae (flyingfish)	H03	T	10-15	10+
<i>Fistularia petimba</i> (cornetfish)	H	V	20-40	2
<i>Globicephala scammoni</i> (pilot whale)	H0	V	375	2
Holocentridae (squirrelfish)	H	R	2	1
Istiophoridae (marlin)	H	T	125	1
<i>Katsuwonus pelamis</i> adult (skipjack tuna)	H3	T	45	1,000+
juvenile	3	RV	10-15	50
<i>Kyphosus cinerascens</i> (sea chub)	H	R	2.5 [†]	13
<i>Manta alfredi</i> (manta ray)	H	V	100-125 [†]	1
<i>Manta</i> sp.	0	V		1

TABLE 3. Continued.

SPECIES, GENUS, OR FAMILY (Common Name in Parentheses)	DRIFT LOCATION	BEHAVIOR CATEGORY	FORK LENGTH (cm)	MAXIMUM NUMBER SEEN AT ONE TIME
<i>Mulloidichthys samoensis</i> (goatfish)	H	RV	10-12	1,000+
<i>Naucrates ductor</i> adult (pilotfish)	H03	RV	15-30	7
juvenile	H03	R	2.6-6.7 [†]	7
<i>Nomeus gronowi</i> (man-of-war fish)	0	V	2	1
<i>Prionace glauca</i> (great blue shark)	0	V	150	1
<i>Psenes cyanophrys</i> (freckled driftfish)	H03	R	1.5-12.4 [†]	1,000+
<i>Remora remora</i> (attached) (remora)	H03	RV	15-30	—
<i>Rhincodon typus</i> (whale shark)	3	V	300	1
<i>Seriola rivoliana</i> [‡] (amberjack)	H	R	20 [†]	1
<i>Seriola dumerili</i> (greater amberjack)	H	R	3.7	1
<i>Sphyræna barracuda</i> (great barracuda)	H	V	50	1
<i>Thunnus albacares</i> (yellowfin tuna)	H3	RV	25-40	37
<i>Tursiops</i> sp. (bottlenose dolphin)	H0	V	150-200	20+

* Drift Location: H = Hawaii; 0 = 0° Latitude; 3 = 3° S.

Behavior Category: R = Resident; V = Visitor; T = Transient.

[†] Measured length; all other lengths are estimated.

[‡] Breadth.

[§] The first record for Hawaiian waters, identified by Dr. Frank J. Mather, Woods Hole Oceanographic Institution, from a specimen preserved after capture at the raft.

TABLE 4. Fish species caught (in pounds) by pole-and-line boats around fish aggregating buoys during 1978 (from Matsumoto et al. 1981).

Buoy	Visits	Species									Total
		Skipjack tuna		Yellowfin tuna		Kawakawa		Dolphin			
		Catch	Catch per visit	Catch	Catch per visit	Catch	Catch per visit	Catch	Catch per visit		
A	92	357,044	3,880.4	22,682	246.5	1,479	16.0	854	9.3	382,031	4,152.5
B	1	5,110	5,110.0	0	0.0	0	0.0	0	0.0	5,110	5,110.0
C	14	103,037	7,359.8	1,475	105.4	4,218	301.3	0	0.0	108,730	7,766.4
D	139	573,106	4,123.1	80,183	576.9	1,706	12.3	3,034	22.6	658,029	4,734.0
Total	246	1,038,297	4,220.7	104,340	424.1	7,403	30.0	3,888	15.8	1,153,900	4,690.6
Percent of total catch		89.73		9.28		0.64		0.34		99.99	

TABLE 5. Species and number of fish caught by trolling boats around fish aggregating buoys, May 1977-July 1979 (from Matsumoto et al. 1981).

Species	Buoy												Percent of total
	A			B			C			Total			
	Visit	Catch	Catch/visit	Visit	Catch	Catch/visit	Visit	Catch	Catch/visit	Visit	Catch	Catch/visit	
Skipjack tuna	309	423	1.37	160	3	0.02	137	55	0.40	606	481	0.79	23.0
Yellowfin tuna		484	1.57		12	0.08		44	0.32		540	0.89	25.9
Bigeye tuna		11	0.04		0	0.00		10	0.07		21	0.04	1.0
Kawakawa		77	0.25		68	0.42		43	0.31		188	0.31	9.0
Dolphin		217	0.70		275	1.72		280	2.04		772	1.27	37.0
Wahoo		30	0.10		8	0.05		2	0.02		40	0.07	1.9
Blue marlin		15	0.05		3	0.02		1	0.01		19	0.03	0.9
Striped marlin		2	0.01		0	0.00		0	0.00		2	0.01	0.1
Spearfish		3	0.01		0	0.00		0	0.00		3	0.01	0.1
Rainbow runner		16	0.05		0	0.00		0	0.00		16	0.03	0.8
Greater amberjack		3	0.01		0	0.00		0	0.00		3	0.01	0.1
Barracuda		2	0.01		0	0.00		0	0.00		2	0.01	0.1
Total	309	1,283	4.15	160	369	2.31	137	435	3.18	606	2,087	3.44	

TABLE 6. Weight and value of products of night handline fishery for tuna (from Yuen 1979).

Species	Weight (t)			Weight (1,000 lb)			Value (\$1,000)		
	1973	1974	1975	1973	1974	1975	1973	1974	1975
Bigeye tuna	65.4	120.2	63.0	144.2	265.0	139.0	102.6	249.8	149.5
Yellowfin tuna	23.3	22.9	75.5	51.3	50.5	166.4	38.0	38.4	157.0
Albacore	0.4	0.2	16.1	0.8	0.4	35.5	0.5	0.2	21.0
All tunas	89.0	143.3	154.6	196.3	315.9	340.9	131.1	288.4	327.5
Squid	5.0	1.7	1.3	11.1	3.7	2.8	6.2	3.5	3.5

TABLE 7. Invertebrates and ascidians collected from within a 0.06 m² area on the concrete shelter portions of the three replication reefs in Santa Monica Bay, 1963 (from Turner et al. 1969).

Number of individuals and their volume, by reef and collection															
HERMOSA BEACH						SANTA MONICA						MALIBU			
June			August			April			August			April		August	
No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)
--	--	--	--	--	--	--	--	--	--	Col.	*15.50	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Col.	<0.05	--	--	--	--	Col.	<0.05	Col.	<0.05	Col.	<0.05	Col.	0.08	--	--
--	--	--	--	--	--	--	--	--	--	133	29.30	--	--	--	--
1	<0.05	--	--	--	--	--	--	--	--	--	--	2	<0.05	--	--
--	--	1	<0.05	--	--	--	--	--	--	2	0.08	--	--	--	--
--	0.60	--	0.50	--	--	--	<0.05	--	0.85	--	3.70	--	1.00	--	--
--	--	--	--	--	--	--	--	--	--	6	--	--	--	--	--
1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	--	9	--	--	--	--	--	--	--	--	--	--	--	--	--
unid. cirratulid	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Flabelligeridae	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Stylariondes inflata</i>	1	5	--	--	--	--	--	--	--	--	--	--	--	--	--
unid. flabelligerid	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lumbrineridae	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	2	--	--	--	--	--	--	--	1	--	--	--	--	--
<i>Lumbrineria</i> sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
unid. lumbrinerid	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nereidae	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Nereis</i> sp.	--	7	--	--	--	--	--	--	--	--	--	--	--	--	--
unid. nereid	--	--	--	--	--	--	--	--	--	3	--	--	--	--	--
Opheleidae	12	10	--	--	--	--	--	--	--	--	--	--	--	--	--
Orbinidae	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Phyllodoctidae	2	3	--	--	--	--	--	--	--	6	--	3	--	--	--

TABLE 7.--Continued.

Number of individuals and their volume, by reef and collection												
HERMOSA BEACH				SANTA MONICA				MALIBU				
Species	June		August		April		August		April		August	
	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)
Annelida—continued												
Polychaeta—continued												
Polynoidae												
<i>Eunoe</i> sp.	5	--	--	--	--	--	--	--	--	--	--	--
<i>Halargyria</i> sp.	--	--	--	--	--	--	--	--	1	--	--	--
und. polynoid	--	--	2	--	--	--	28	--	--	--	61	--
Sabellariidae	7	--	--	--	--	--	--	--	--	--	--	--
<i>Sabellaria cementarium</i>	--	--	--	--	--	--	3	--	--	--	--	--
und. sabellariid	--	--	8	--	--	--	--	--	--	--	--	--
Sabellidae	2	--	--	--	--	--	--	--	--	--	--	--
<i>Sabella</i> sp.	--	--	4	--	--	--	--	--	--	--	1	--
und. sabellid	--	--	--	--	--	--	--	--	--	--	--	--
Serpulidae	--	--	--	--	--	--	--	--	3	--	--	--
<i>Spirorbanchus spinosus</i>	--	--	--	--	--	--	--	--	--	--	--	--
Spionidae	3	--	--	--	--	--	--	--	2	--	--	--
<i>Polydora</i> sp.	--	--	2	--	--	--	--	--	--	--	1	--
und. spionid	--	--	--	--	--	--	--	--	--	--	--	--
Syllidae	--	--	--	--	--	--	--	--	--	--	--	--
Arthropoda												
Crustacea												
Cirripedia												
<i>Balanus aquila</i>	51	57.65	45	1.80	28	137.50	1	10.69	8	13.00	--	--
<i>Balanus concavus pacificus</i>	--	--	--	--	64	62.50	15	8.70	35	5.10	4	0.80
<i>Balanus flae.</i>	--	--	--	--	1	0.08	--	--	--	--	--	--
<i>Balanus tintinnabulum californicus</i>	--	--	--	--	1	0.60	--	--	--	--	--	--
<i>Balanus trigonus</i>	--	--	15	0.85	--	--	--	--	20	1.60	2	0.30
Tanaidacea	67	0.05	185	0.15	--	--	--	--	--	--	5	<0.05
<i>Leptochelia</i> sp.	--	--	--	--	--	--	--	--	--	--	--	--
Isopoda	1	<0.05	--	--	--	--	--	--	--	--	--	--
valviferan	--	--	--	--	--	--	--	--	--	--	--	--
Amphipoda	48	0.05	11	<0.05	--	0.08	--	<0.05	--	--	28	0.05
Gammaridea	12	--	2	--	45	--	21	--	3	<0.05	10	0.05
Caprellidea	--	--	--	--	4	--	--	--	--	--	--	--

TABLE 7.--Continued.

Species	Number of individuals and their volume, by reef and collection									
	HERMOSA BEACH					SANTA MONICA				
	June		August			April		August		
	No.	Vol. (ml)	No.	Vol. (ml)		No.	Vol. (ml)	No.	Vol. (ml)	
Decapoda										
<i>Alpheus dentipes</i>	--	--	--	0.50	1	--	--	--	--	8
<i>Cancer anthonyi</i>	--	--	--	0.10	2	--	--	--	--	--
<i>Cancer jordanii</i>	--	--	6	<0.05	--	--	0.10	1	0.10	--
<i>Cancer sp.</i>	--	--	2	0.08	--	--	0.70	2	0.70	--
<i>Loxostichus crispatus</i>	--	--	1	<0.05	--	--	--	--	--	3
Pycnogonida										
<i>Chama pellucida</i>	--	--	--	--	--	--	--	4	0.90	1
Pelecypoda										
<i>Chione sp.</i>	1	<0.05	--	0.15	--	--	--	--	--	--
<i>Hiatella arctica</i>	34	<0.05	15	0.08	3	3	<0.05	13	0.70	12
<i>Kalappa laevis</i>	5	<0.05	--	--	3	3	<0.05	3	<0.05	10
<i>Leptopoda latiauratus</i>	--	--	1	--	--	--	--	1	<0.05	--
<i>Lima hemphilli</i>	--	--	1	<0.05	--	--	--	--	--	--
<i>Modiolus carpi</i>	1	<0.05	3	<0.05	--	--	--	--	--	1
<i>Petricola sp.</i>	2	<0.05	1	<0.05	--	--	--	--	--	--
<i>Parvicula tenuisculpta</i>	2	<0.05	23	0.05	--	--	--	3	4.20	--
<i>Pododemus erpa</i>	1	0.18	--	--	--	--	--	--	--	1
<i>Saxidomus nutalli</i>	--	--	--	--	--	--	--	--	--	--
Gastropoda										
<i>Acanthodoris lutea</i>	2	<0.05	--	--	--	--	--	--	--	--
<i>Amphidoris verticilaris</i>	--	--	35	0.05	--	--	--	--	--	--
<i>Conus californicus</i>	--	--	4	0.08	--	--	--	--	--	--
<i>Crepidula lingulata</i>	19	0.55	65	1.10	4	4	0.05	2	0.08	3
<i>Dendronotus frontosus</i>	1	<0.05	--	--	--	--	--	--	--	--
<i>Epitonium bellistriatum</i>	--	--	1	<0.05	--	--	--	--	--	--
<i>Epitonium aspinosus</i>	--	--	3	<0.05	--	--	--	--	--	--
<i>Fusinus bradyi</i>	--	--	2	0.20	--	--	--	1	0.15	3
<i>Hermisenda erassioris</i>	--	--	1	<0.05	--	--	--	--	--	--
<i>Marunellum eridicticum</i>	--	--	--	--	--	--	--	--	--	--
<i>Murella tuberosa</i>	2	<0.05	17	0.10	--	--	--	1	<0.05	--
<i>Nassarius perpinguis</i>	--	--	4	0.10	--	--	--	1	<0.05	9
<i>Olivella badia</i>	--	--	5	<0.05	1	1	<0.05	--	0.30	1
<i>Retusa sp.</i>	1	<0.05	--	--	--	--	--	--	--	--
<i>Serpulorbis squamigerus</i>	--	--	10	0.05	--	--	--	--	--	--
<i>Turbonilla kelseyi</i>	--	--	--	--	--	--	--	--	--	--
Ectopocrea										
<i>Crinia sp.</i>	--	--	Col.	0.30	--	--	--	Col.	0.80	Col.
<i>Diaperocrea floridana</i>	--	--	--	--	--	--	--	--	--	Col.
<i>Scrupocellaria diogenesi</i>	--	--	--	--	--	--	--	--	--	Col.
<i>Victorella argilla</i>	Col.	70.75	Col.	16.60	Col.	48.45	41.60	Col.	7.10	Col.
Phoronidea										
<i>Phoronis sp.</i>	20	0.40	125	2.70	6	6	<0.05	18	0.15	225

TABLE 7.--Continued.

Species	Number of individuals and their volume, by reef and collection									
	HERMOSA BEACH				SANTA MONICA				MALIBU	
	June		August		April		August		April	
	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)	No.	Vol. (ml)
Echinodermata										
Ophiuroidea										
<i>Ophiaster spiculata</i>	--	--	--	--	--	--	--	--	1	<0.05
Holothuroidea										
<i>Eupentacta quinquevittata</i>	--	--	7	0.10	--	--	--	--	--	--
Chordata										
<i>Funicularia</i>										
<i>Pyros hawaiiensis</i>	--	--	1	0.30	--	--	--	--	1	0.30
Total species	32	129.77+	40	25.26+	14	249.28+	20	62.67+	30	83.55
Total volume	--	--	--	--	--	--	--	--	--	--

• Col. = colony.

TABLE 8. Fishes recorded during underwater fish transects at the four artificial reefs between 1960 and 1973 (from Kanayama and Onizuka 1973).

Common Name, Local Name	Scientific Name	Artificial Reef				
		Maunaloa Bay, Oahu	Keawakapu, Maui	Waianae, Oahu	Kualoa, Oahu	
Shark, Mano	CARCHARHINIDAE (unident.)			X		
Eagle ray, Hihimanu	Aetobatus narinari	X		X		
Lizardfish, 'Ulae	SYNODONTIDAE (unident.)	X		X		
Lizardfish, 'Ulae	Synodus variegatus	X		X		
Lizardfish, 'Ulae	S. dermatogenys	X				
Moray eel, Puhi-paka	Gymnothorax flavimarginatus	X	X	X		
Moray eel, Puhi-oni'o	G. meleagris	X				X
Moray eel, Puhi	G. steindachneri	X		X		
Moray eel, Puhi-kapa	Echidna nebulosa	X				
Moray eel, Puhi	Echidna sp.			X		
White eel, Puhi-uha	Conger marginatus			X		
Cornetfish, Nunu peke	Fistularia petimba	X		X		
Trumpetfish, Nunu	Aulostomus chinensis	X	X	X		
Squirrelfish, 'Ala'ihī	Holocentrus ensifer		X			
Squirrelfish, 'Ala'ihī maoli	H. xantherythrus	X		X		X
Squirrelfish, 'Ala'ihī kalaloa	H. diadema	X				
Squirrelfish, 'Ala'ihī	Holocentrus sp.			X		
Squirrelfish, 'U'u	Myripristis berndti	X	X	X		X
Squirrelfish, 'U'u	M. argyromus	X				
Barracuda, Kaku	Sphyræna barracuda		X			
Barracuda, Kawalea	S. helleri		X	X		
Flatfish, Paku	BOTHIDAE (unident.)	X	X			
Flatfish, Paku	PLEURONECTIDAE (unident.)		X			
Flatfish, Paku	(unidentified)			X		
Grouper	Caesioperca thompsoni	X		X		X
Introduced grouper, Roi	Cephalopholis argus	X		X		
Introduced grouper, Rero	C. urodelus	X				
Introduced grouper, Tarao/Tarao-au	Epinephelus merra/hexagonatus	X				
Big eye, 'Aweoweo	Priacanthus cruentatus	X	X	X		
Big eye, 'Aweoweo	P. meeki	X				
Cardinalfish, 'Upapalu	Apogon snyderi	X	X			
Quakerfish, Maka-a	Malacanthus hoedtii	X		X		
Amberjack, Kahala	Seriola dumerilii	X		X		
Mackerel scad, 'Opelu	Decapterus pinnulatus	X	X	X		
Jack crevally, White ulua	Carangoides ajax		X	X		
Jack crevally, Ulua	C. ferdau		X	X		
Jack crevally, 'Omilu	Caranx melampygus	X	X	X		
Jack crevally, Ulua	C. lugubris		X			
Jack crevally, Pa'opa'o	Gnathonodon speciosus		X			
Snapper, Uku	Aprion virescens	X	X	X		
Snapper, Gurutsu	Aphareus furcatus	X		X		
Introduced snapper, Toau	Lutjanus vaigiensis	X	X			
Introduced snapper, Tuhara	L. gibbus	X	X			

TABLE 8.--Continued.

Common Name, Local Name	Scientific Name	Artificial Reef				
		Maunaloa Bay, Oahu	Keawakapu, Maui	Waianae, Oahu	Kualoa, Oahu	
Goatfish, Weke-'a'a	Mulloidichthys samoensis	X	X	X	X	
Goatfish, Weke-'ula	M. auriflamma	X	X	X		
Goatfish, Moelua	M. pflugeri	X				
Goatfish, Malu	Parupeneus pleurostigma	X	X	X		
Goatfish, Kumu	P. porphyreus	X	X	X		
Goatfish, Munu	P. bifasciatus	X		X		
Goatfish, Moano	P. multifasciatus	X	X	X	X	
Goatfish, Moano kea	P. chryserydros	X		X		
Porgy, Mu	Monotaxis grandoculis	X	X	X		
Convictfish, stripey	Microcanthus strigatus		X	X		
Black banded angelfish	Holacanthus arcuatus			X	X	
Russet angelfish	Centropyge potteri	X	X	X	X	
Butterflyfish, Lau-wiliwili- nukunuku-'oi'oi	Forcipiger longirostris	X	X	X		
Butterflyfish, False kihikihi	Heniochus acuminatus	X	X	X		
Butterflyfish	Hemitaurichthys zoster			X		
Orange striped butterflyfish	Chaetodon ornatissimus	X		X		
Blue striped butterflyfish	C. fremblii	X	X	X	X	
Cross striped butterflyfish	C. auriga	X	X			
Butterflyfish	C. trifasciatus	X				
Butterflyfish	C. multicinctus	X		X		
Butterflyfish	C. lunula	X		X		
Butterflyfish	C. corallicola	X	X	X	X	
Butterflyfish	C. miliaris	X	X	X	X	
Hawkfish, Pili-ko'a	Paracirrhites cinctus	X		X	X	
Hawkfish, Pili-ko'a	P. fosteri	X		X	X	
Hawkfish, Pili-ko'a	P. arcatus	X		X	X	
Damselfish, Maomao	Abudefduf abdominalis	X		X		
Damselfish	A. imparipennis	X				
Damselfish	Pomacentrus jenkinsi	X		X		
Damselfish, 'Alo'ilo'i	Dascyllus albisella	X	X	X	X	
Damselfish	Plectroglyphidodon johnstonianus			X		
White tailed damselfish	Chromis leucurus	X	X	X		
Black damselfish	C. verater	X	X	X	X	
Blue damselfish	C. ovalis	X	X	X	X	
Damselfish	C. vanderbilti	X	X	X		
Wrasse, Kupoupou	Cheilio inermis	X		X		
Wrasse, 'A'awa	Bodianus bilunulatus	X	X	X		
Birdfish, Hinalea i'iwi	Gomphosus varius			X		
Wrasse	Pseudocheilinus evanidus	X				
Wrasse	P. octotaenia	X				
Wrasse, Hinalea lolo	Coris gaimardi	X		X		
Wrasse, Hilu	C. flavovittata	X		X		
Wrasse	C. venusta	X		X		
Wrasse, 'Opule	Anampses cuvieri	X	X	X		

TABLE 8.--Continued.

Common Name, Local Name	Scientific Name	Artificial Reef				
		Maunaloa Bay, Oahu	Keawakapu, Maui	Waianae, Oahu	Kualoa, Oahu	
Wrasse	Anampses rubrocaudatus	X	X	X		
Wrasse, 'Opule	A. godeffroyi	X	X			
Wrasse, Lae-nihi	Iniistius pavoninus	X	X			
Cleaner wrasse	Labroides phthiropagus	X	X	X		
Wrasse	Novaculichthys taeniourus	X		X		
Wrasse, Hinalea lau-wili	Thalassoma duperreyi	X	X	X	X	
Wrasse, Hinalea luahine	T. ballieui	X		X		
Wrasse	T. umbrostigma	X				
Wrasse, 'Omaka	Stethojulis albobittata	X		X		
Wrasse, 'Omaka	S. axillaris	X				
Wrasse, Po-ou	Cheilinus rhodochrous	X	X			
Wrasse, Po-ou	C. bimaculatus	X	X			
Wrasse, La-o	Haliocleres ornatissimus			X		
Wrasse, Lae-nihi	Hemipteronotus baldwini	X		X		
Wrasse, Hinalea 'aki-lolo	Macropharyngodon geoffroyi			X		
Parrotfish, Uhu	SCARIDAE (unident.)	X				
Parrotfish, Uhu	Scarus dubius	X	X	X		
Parrotfish, Uhu uliuli	S. perspicillatus	X	X	X		
Parrotfish, Uhu	S. sordidus	X		X		
Parrotfish, Uhu	S. ahula	X				
Parrotfish, Uhu	Calotomus sandvicensis	X	X			
Moorish idol, Kihikihi	Zanclus canescens	X	X	X		
Surgeonfish	ACANTHURIDAE (unident.)	X				
Surgeonfish, Surf maiko	Acanthurus guttatus	X				
Surgeonfish, Paku'iku'i	A. achilles	X		X		
Surgeonfish, Maikoiko	A. leucopareius	X	X	X		
Surgeonfish, Maiko	A. nigrofuscus	X		X	X	
Surgeonfish, Maiko	A. nigroris	X	X	X		
Surgeonfish, Na'en'e	A. olivaceus	X	X	X	X	
Surgeonfish, Palani	A. dussumieri	X	X	X	X	
Convict tang, Manini	A. sandvicensis	X		X	X	
Surgeonfish, Pualu	A. xanthopterus	X		X		
Surgeonfish, Pualu	A. mata	X	X	X		
Surgeonfish, Kala	Naso hexacanthus	X	X	X		
Surgeonfish, Kala	N. brevirostris	X	X	X		
Surgeonfish, Kala	N. unicornis		X	X		
Surgeonfish, Kala	N. lituratus	X		X		
Yellow tang, Lau'i-pala	Zebrasoma flavescens	X		X		
Surgeonfish, Kole	Ctenochaetus strigosus	X	X	X		
Triggerfish, Humuhumu-umauma-lei	Balistes bursa	X	X	X	X	
Triggerfish, Humuhumu-uli	B. nycteris			X		
Triggerfish, Humuhumu-mimi	B. capistratus	X	X	X		
Triggerfish, Humuhumu	B. fuscus		X	X		
Triggerfish, Humuhumu	Balistes sp.			X		

TABLE 8.--Continued.

Common Name, Local Name	Scientific Name	Artificial Reef			
		Maunaloa Bay, Oahu	Keawakapu, Maui	Waianae, Oahu	Kualoa, Oahu
Triggerfish, Humuhumu-uli	Melichthys vidua			X	
Triggerfish, Humuhumu-'ele'ele	M. buniva	X		X	
Triggerfish, Humuhumu-nukunuku-a-pua'a	Rhinecanthus aculeatus	X		X	
Triggerfish, Humuhumu-nukunuku-a-pua'a	R. rectangulus	X			
Triggerfish	Xanthichthys ringens			X	
Filefish	Amanses sandwichiensis	X			
Filefish	A. carolae	X			
Filefish, 'O'ili lepa	Alutera scripta	X	X	X	
Filefish, 'O'ili uwiwi	Pervagor spilosoma	X	X	X	
Boxfish, Moa	Ostracion lentiginosus	X		X	
Cowfish, Makukana	Lactoria fornasini	X			
Puffer, 'O'opu-hue	Arothron hispidus	X	X	X	
Sharpback puffer	Canthigaster cinctus	X	X	X	
Sharpback puffer	C. jactator	X	X	X	X
Sharpback puffer	C. rivulatus	X	X	X	
Sharpback puffer, Pu'u-u-ola'i	C. amboinensis			X	
Spiny puffer, 'O'opu-kawa	Diodon hystrix	X	X	X	
Blenny	BLENNIDAE (unident.)	X			
Blenny	Runula goslinei			X	
Frogfish	Antennarius moluccensis	X			
Spiny lobster, Ula	Panulirus japonicus	X		X	
Spiny lobster, Ula	P. penicillatus			X	
Octopus, Hee	Octopus cyanea	X			
Crown-of-thorns starfish	Acanthaster planci	X		X	
Total Species:		126	70	114	24
Total Species Recorded at all Artificial Reefs:		156			

TABLE 9. Summary of fish counts at the four artificial reefs (from Kanayama and Onizuka 1973).

ARTIFICIAL REEFS											
		Maunalua Bay		Keawākapu		Cars		Waianae		Kialoa	
Year	Date	No. of Species	Pounds per Acre	No. of Species	Pounds per Acre	No. of Species	Pounds per Acre	No. of Species	Pounds per Acre	No. of Species	Pounds per Acre
1960	8/24	20	37								
1961	3/16	45	1,585								
	5/12	46	829								
	9/14	47	936								
	12/20	38	627								
1962	3/01			6	3						
	4/17			(Pre-Reef Count)		32	103	32	103		
1963	3/06										
	9/19			12	11	24	1,423				
	9/27	36	774								
	10/22			20	356						
1964	2/17			24	131						
	2/18			19	102						
	3/13					19	2,631				
	4/03	31	583								
	9/16			29	446						
	9/30					33	491				
	10/09	43	528					50	711		
	10/13										
1965	3/17			29	555						
	3/29										
	4/19	36	1,390			29	1,084				
	6/10							24	48		
	6/30							37	662		
	8/31							35	176		
	10/07			24	98						
	10/08			22	77						
	10/29							42	412		

TABLE 10A. Fishes recorded at Stage I off Panama City, Florida, with estimates of usual abundance and habitat occupied (from Hastings et al. 1976).

Species	Abundance ¹				Habitat ¹
	Spring (Apr.)	Summer-fall (July-Nov.)	Winter		
			Dec.	Jan.	
Carcharhinidae:					
• <i>Carcharhinus milberti</i>	—	few	—	—	O
Dasyatidae:					
<i>Dasyatis</i> sp.	—	few	—	—	B
Muraenidae:					
<i>Gymnothorax nigromarginatus</i>	—	few	few	—	B
Clupeidae:					
<i>Sardinella anchovia</i>	—	com-abun	abun	—	U
Ariidae:					
<i>Arius felis</i>	—	sev	—	—	B
Batrachoididae:					
<i>Opsanus pardus</i>	sev	sev	sev	com	B
Antennariidae:					
<i>Antennarius ocellatus</i>	few	few	few	few	B
Ogcocephalidae:					
<i>Ogcocephalus radiatus</i>	—	few	few	few	B
Serranidae:					
<i>Centropristis ocyurus</i>	com	com	com	com	B
<i>Diplectrum formosum</i>	sev	sev-com	sev-com	—	B
<i>Epinephelus nigritus</i>	—	—	—	few	L
<i>Mycteroperca microlepis</i>	—	few-com	few	sev	L
<i>Serranus subligarius</i>	sev	sev-com	sev-com	com	B-P
Grammistidae:					
<i>Rypticus maculatus</i>	—	sev-com	sev	com	B-P
Apogonidae:					
<i>Apogon pseudomaculatus</i>	few	sev-com	—	sev	B
Rachycentridae:					
<i>Rachycentron canadum</i>	—	few	few	—	O-U
Echeneidae:					
<i>Echeneis neucratoides</i>	—	few-sev	—	sev	(²)
Carangidae:					
<i>Caranx crysos</i>	—	com	—	—	U
<i>Caranx hippos</i>	—	sev-com	—	—	O-U
<i>Caranx ruber</i>	—	few-com	few	—	U
<i>Decapterus punctatus</i>	—	com-abun	abun	few	U
<i>Elagatis bipinnulata</i>	—	sev	sev	few	O-U
<i>Seriola dumerili</i>	sev	few-com	com	com-abun	L-O-U
<i>Seriola rivoliana</i>	—	—	few	—	U
<i>Trachurus lathami</i>	—	com	—	—	L
Lutjanidae:					
<i>Lutjanus campechanus</i>	—	few	few	—	L
• <i>Lutjanus griseus</i>	few	sev-abun	few	sev	L-U
<i>Rhomboplites aurorubens</i>	sev	com-abun	—	com	L
Pomadasyidae:					
<i>Haemulon aurolineatum</i>	com	com-abun	com-abun	sev	L
<i>Haemulon plumieri</i>	—	—	few-sev	—	L
Spandae:					
<i>Archosargus probatocephalus</i>	—	few	—	—	U
<i>Lagodon rhomboides</i>	—	sev	—	—	L-U
Sciaenidae:					
<i>Equetus lanceolatus</i>	—	sev-com	—	com	B
<i>Equetus umbrosus</i>	com	sev-com	com	com	B
<i>Equetus</i> sp. ³	—	few	—	—	B
Kyphosidae:					
<i>Kyphosus sectatrix</i>	—	sev	—	—	U
Ephippidae:					
<i>Chaetodipterus faber</i>	com	sev-com	sev	com	L-U
Chaetodontidae:					
<i>Chaetodon ocellatus</i>	few	few	few	few	B-P
<i>Chaetodon sedentarius</i>	—	few	few	—	B
<i>Holacanthus bermudensis</i>	sev	sev-com	sev	sev	L-U
Pomacentridae:					
• <i>Abudefduf saxatilis</i>	—	few-sev	—	sev	P
<i>Chromis enchrysurus</i>	—	few	—	few	B
<i>Chromis scotti</i>	—	sev-com	—	sev	B-P
<i>Pomacentrus partitus</i>	—	few-sev	—	—	P
<i>Pomacentrus variabilis</i>	com	sev-com	sev	com	B-P
Labridae:					
<i>Halichoeres caudalis</i>	com	sev-com	—	few	B
<i>Thalassoma bifasciatum</i>	—	few-sev	—	sev	P
Sphyraenidae:					
<i>Sphyraena barracuda</i>	—	sev-abun	sev	few	O-U
Blennidae:					
<i>Blennius marmoratus</i>	—	sev	—	—	B-P
<i>Hypleurochilus geminatus</i>	few	few-com	—	—	P

TABLE 10A.--Continued.

Species	Abundance ¹				Habitat ¹
	Spring (Apr.)	Summer-fall (July-Nov.)	Winter		
			Dec.	Jan.	
Gobiidae:					
<i>Coryphopterus punctipectophorus</i>	few	few	—	—	B
<i>loglossus calliurus</i>	—	sev	—	—	B
Acanthuridae:					
<i>Acanthurus coeruleus</i>	—	—	—	few	P
Scombridae:					
<i>Euthynnus alletteratus</i>	—	sev-com	sev	sev	O-U
Bothidae:					
<i>Paralichthys albigutta</i>	—	few	—	—	B
Balistidae:					
<i>Balistes capricus</i>	few	few-sev	few	few	L-U
<i>Monacanthus hispidus</i>	—	few-sev	—	—	P
Ostraciidae:					
<i>Lactophrys quadricornis</i>	few	few	few	—	B
Tetraodontidae:					
<i>Canthigaster rostrata</i>	—	few	—	—	B
<i>Sphoeroides spengleri</i>	—	few	—	—	B
Diodontidae:					
<i>Chilomycterus schoepfi</i>	few	few	few	few	B
61 species	21 species	57 species	31 species	32 species	
100%	34%	93%	51%	52%	
Number of observations	1	6	2	1	
Temperature range	17°-20°C	23°-29°C	18°-19°C	18°C	

¹Abbreviations are as follows: sev-several, com-common, abun-abundant, B-on bottom, L-lower water column, P-on pilings, O-open water around platform, U-middle to upper water column under platform.

²*Echeneis neucratoides* on *Epinephelus*, *Sphyaena*, *Seriola*, *Balistes*, and *Caretta*.

³*Equetus* sp. - an undescribed species listed by Bullis and Thompson (1965) as "*Equetus* sp. nov." and by Struhsaker (1969) as "Blackbar drum *Pareques* sp. (undescribed)."

TABLE 10B. Fishes recorded at Stage II off Panama City, Florida, with estimates of usual abundance and habitat occupied (from Hastings et al. 1976).

Species	Abundance ¹				Habitat ¹
	Spring (Apr.-May)	Summer-fall (June-Nov.)	Winter		
			Dec.	Feb.	
Carcharhinidae	—	few	—	—	O
Sphyrnidae:					
• <i>Sphyrna</i> sp.	—	few	—	—	O
Dasyatidae:					
• <i>Dasyatis</i> sp.	—	few	—	—	B
Rajidae:					
• <i>Raja eglanteria</i>	—	few	few	—	B
Muraenidae:					
• <i>Gymnothorax nigromarginatus</i>	few	few	few	—	B
Congridae	—	—	few	—	B
Ophichthidae:					
• <i>Mystriophis interinctus</i>	few	few	few	—	B
Clupeidae:					
• <i>Etrumeus teres</i>	—	sev-com	—	—	U
• <i>Harengula pensacolae</i>	—	sev-abun	sev-com	—	L-U
• <i>Opisthonema oglinum</i>	sev	com	—	—	U
• <i>Sardinella anchovia</i>	com-abun	com-abun	sev-abun	—	U
Engraulidae	—	com-abun	—	—	L-U
Ariidae:					
• <i>Arius felis</i>	—	few-abun	—	—	B
Batrachoididae:					
• <i>Opsanus pardus</i>	few-sev	few	few-com	—	B
Antennariidae:					
• <i>Antennarius ocellatus</i>	few	few	few-com	—	B
Ogcocephalidae:					
• <i>Ogcocephalus radiatus</i>	few	few	few	—	B
Syngnathidae:					
• <i>Syngnathus</i> sp.	—	few	—	—	O
Serranidae:					
• <i>Centropristis melana</i>	few	sev	few-sev	sev	B
• <i>Centropristis ocyurus</i>	com	com-abun	com	com	B
• <i>Centropristis philadelphica</i>	—	—	few	—	B
• <i>Diplectrum formosum</i>	sev-com	few-com	sev	sev	B
• <i>Epinephelus morio</i>	few	few	few	—	B-L
• <i>Epinephelus</i> sp. ²	—	few	—	—	B
• <i>Mycteroperca microlepis</i>	few	few-sev	few-sev	—	L
• <i>Serranus subligarius</i>	sev	sev-com	sev-com	few	B-P
Grammistidae:					
• <i>Rypticus maculatus</i>	—	few-com	few-com	—	B-P
Priacanthidae:					
• <i>Priacanthus arenatus</i>	—	few	—	—	B
Apogonidae:					
• <i>Apogon pseudomaculatus</i>	few	few-com	few-sev	—	B
Pomatomidae:					
• <i>Pomatomus saltatrix</i>	few-sev	—	few	—	O-U
Rachycentridae:					
• <i>Rachycentron canadum</i>	—	few-sev	—	—	O-U
Echeneidae:					
• <i>Echeneis neucratoides</i>	—	few	—	—	(?)
Carangidae:					
• <i>Caranx bartholomaei</i>	—	few-sev	few	—	L-U
• <i>Caranx crysos</i>	—	sev-abun	few	—	U
• <i>Caranx hippos</i>	—	com	sev	—	O-U
• <i>Caranx ruber</i>	—	few-com	—	—	U
• <i>Decapterus punctatus</i>	com-abun	abun	com-abun	com	L-U
• <i>Selar crumenophthalmus</i>	—	sev-com	—	—	L-U
• <i>Seriola dumerili</i>	few	few-sev	sev	—	L-O-U
• <i>Seriola zonata</i>	few	—	—	—	U
• <i>Trachurus lathami</i>	com	com	few-abun	—	L
Lutjanidae:					
• <i>Lutjanus campechanus</i>	—	few-sev	sev	—	L
• <i>Lutjanus griseus</i>	—	sev	few-sev	—	L-U
• <i>Lutjanus synagris</i>	—	few	—	—	L
• <i>Rhomboplites aurorubens</i>	sev	sev-com	few-sev	—	L-U
Lobotidae:					
• <i>Lobotes surinamensis</i>	—	few	—	—	U
Pomadasyidae:					
• <i>Haemulon aurolineatum</i>	com	com-abun	few-com	few	L
• <i>Haemulon plumieri</i>	few-sev	few-sev	few	—	L
• <i>Orthopristis chrysoptera</i>	com	abun	few-abun	—	L
Spandae:					
• <i>Archosargus probatocephalus</i>	few	sev	few	—	L-U
• <i>Calamus-Pagrus</i>	—	few	few	—	L
• <i>Diplodus holbrooki</i>	—	few-sev	few	—	U
• <i>Lagodon rhomboides</i>	m	sev-com	sev-com	sev	L-U
• <i>Stenotomus caprinus</i>	—	com	—	—	B-O

TABLE 10B.--Continued.

Species	Abundance ¹				Habitat ¹
	Spring (Apr.)	Summer-fall (July-Nov.)	Winter		
			Dec.	Jan.	
Sciaenidae:					
<i>Equetus lanceolatus</i>	few-sev	few-com	few-com	com	B
<i>Equetus umbrosus</i>	sev	sev-com	few-sev	—	B
<i>Leiostomus xanthurus</i>	—	com	sev	—	B
<i>Sciaenops ocellata</i>		few	few		B
Mullidae	—	few	—	—	O
Kyphosidae:					
<i>Kyphosus sectatrix</i>	—	few-sev	—	—	U
Ephippidae:					
<i>Chaetodipterus faber</i>	sev	few-com	sev	—	L-U
Chaetodontidae:					
<i>Chaetodon ocellatus</i>	—	few	few	—	B
<i>Holacanthus bermudensis</i>	sev-com	few-com	sev-com	sev	L-U
Pomacentridae:					
<i>Pomacentrus variabilis</i>	sev-com	sev-com	few-sev	—	B-P
Labridae:					
<i>Halichoeres bivittatus</i>	few	few-com	few	—	B
<i>Halichoeres caudalis</i>	sev	sev-com	few-sev	sev	B
<i>Hemipteronotus novacula</i>	—	few	few	—	B
<i>Lachnolaimus maximus</i>	—	few	—	—	L
Sphyraenidae:					
<i>Sphyraena barracuda</i>	—	few-sev	—	—	L-O-U
<i>Sphyraena borealis</i>	—	sev	—	—	U
Polynemidae:					
<i>Polydactylus octonemus</i>	—	—	sev	—	O
Blenniidae:					
<i>Blennius marmoreus</i>	few	few-sev	few	—	P
<i>Hypleurochilus geminatus</i>	sev-com	sev-com	—	—	P
Acanthuridae:					
<i>Acanthurus chirurgus</i>	—	few	—	—	B-P
Scombridae:					
<i>Euthynnus alletteratus</i>	sev-com	sev-com	few-com	—	O
<i>Scomber japonicus</i>	com	com	few	—	U
<i>Scomberomorus cavalla</i>	—	sev	—	—	O
Stromateidae:					
<i>Peprilus burti</i>	few-sev	sev	—	—	U
Scorpaenidae:					
<i>Scorpaena brasiliensis</i>	—	few	few	—	B
Triglidae:					
<i>Prionotus</i> sp.	—	few	—	—	B
Bothidae:					
<i>Paralichthys albigutta</i>	sev	few-sev	sev	few	B
<i>Syacium papillosum</i>	—	few	—	—	B
Balistidae:					
<i>Balistes capriscus</i>	few-sev	few-com	few-sev	few	L-U
<i>Cantherhines pullus</i>	—	few	few	—	P
<i>Monacanthus hispidus</i>	—	few	sev	—	L-P
Ostraciidae:					
<i>Lactophrys quadricornis</i>	few	few-sev	few	—	B
Diodontidae:					
<i>Chilomycterus schoepfi</i>	few	few-sev	few	few	B
86 taxa	41 species	81 taxa	57 taxa	13 species	
100%	48%	94%	66%	15%	
Number of observations	3	13	4	1	
Temperature range	17°-20°C	20°-30°C	15°-19°C	13°C	

¹Abbreviations are as follows: sev - several, com - common, abun - abundant, B - on bottom, L - lower water column, P - on pilings, O - open water around platform, U - middle to upper water column under platform.

²*Epinephelus* sp. - A juvenile apparently either *E. flavolimbatus* or *E. niveatus* based upon color pattern (brownish with small white spots on lateral surface and a dark saddle on caudal peduncle, Smith 1971).

³*Etcheneis neucratoides* on *Caranx* and *Sphyraena*.

TABLE 11. Summary of major game species caught at oil rig platforms by bottom, drift, and troll fishing in nearshore and blue water areas (from Dugas et al. 1979).

Species	Bottom		Drift		Trolling	
	Nearshore	Blue-water	Nearshore	Blue-water	Nearshore	Blue-water
Shark (several species)			X	X		
<i>Arius felis</i> (sea catfish)	X					
<i>Bagre marinus</i> (gafftopsail catfish)	X					
<i>Epinephelus</i> spp. (grouper)		X				
<i>Mycteroperca phenax</i> (scamp)		X				
<i>Pomatomus saltatrix</i> (bluefish)			X		X	
<i>Rachycentron canadum</i> (cobia)			X			
<i>Caranx crysos</i> (blue runner)			X		X	
<i>Caranx hippos</i> (crevalle jack)			X		X	
<i>Seriola dumerili</i> (greater amberjack)		X		X		X
<i>Coryphaena hippurus</i> (dolphin)						X
<i>Lutjanus campechanus</i> (red snapper)	X	X				
<i>Lutjanus griseus</i> (gray snapper)	X	X				
<i>Lutjanus synagris</i> (lane snapper)		X				
<i>Archosargus probatocephalus</i> (sheepshead)	X					
<i>Cynoscion arenarius</i> (sand seatrout)	X					
<i>Cynoscion nebulosus</i> (speckled seatrout)	X					
<i>Cynoscion nothus</i> (silver seatrout)	X					
<i>Menticirrhus americanus</i> (southern kingfish)	X					
<i>Micropogon undulatus</i> (Atlantic croaker)	X					
<i>Pogonias cromis</i> (black drum)	X					
<i>Sciaenops ocellata</i> (red drum)			X			
<i>Sphyrna barracuda</i> (great barracuda)				X		X
<i>Acanthocybium solanderi</i> (wahoo)						X
<i>Euthynnus alleteratus</i> (little tuna)					X	
<i>Sarda sarda</i> (Atlantic bonito)			X		X	
<i>Scomberomorus cavalla</i> (king mackerel)			X		X	
<i>Scomberomorus maculatus</i> (Spanish mackerel)					X	
<i>Thunnus albacares</i> (yellowfin tuna)				X		
<i>Thunnus atlanticus</i> (blackfin tuna)		X		X		
<i>Istiophorus platypterus</i> (sailfish)						X
<i>Makaira nigricans</i> (blue marlin)						X
<i>Tetrapturus albidus</i> (white marlin)						X

TABLE 12. Endangered and threatened species of candidate sites (from Sullivan et al. 1981).

Scientific Name	Common Name	Status*	Distribution
MARINE MAMMALS			
<u>Balaenoptera musculus</u>	Blue whale	E	Oceanic, Pacific, Atlantic
<u>Balaenoptera borealis</u>	Sei whale	E	Oceanic, Pacific, Atlantic
<u>Balaenoptera physalus</u>	Finback whale	E	Oceanic, Southern Hemisphere
<u>Eubalaena glacialis</u>	Right whale	E	Oceanic, Pacific, Atlantic
<u>Megaptera novaeangliae</u>	Humpback whale	E	Oceanic, Caribbean, North Pacific, Atlantic
<u>Physeter catodon</u>	Sperm whale	E	Oceanic, Caribbean, Pacific, Atlantic
<u>Trichechus manatus</u>	Caribbean manatee	E	Off Florida, Caribbean
<u>Monachus schauinslandi</u>	Hawaiian monk seal	E	Northwest Hawaiian Islands (NWHI)
<u>Monachus tropicalis</u>	Caribbean monk seal	E	Caribbean (extinct ?)
SEA TURTLES			
<u>Chelonia mydas</u>	Green sea turtle	T E	Hawaii Florida
<u>Eretmochelys imbricata</u>	Hawksbill	E	Tropical Pacific, Caribbean
<u>Dermochelys coriacea</u>	Leatherback	E	Tropical Pacific, Caribbean

* E = Endangered
T = Threatened

TABLE 12.--Continued.

Scientific Name	Common Name	Status	Distribution
SEA TURTLES			
<u>Lepidochelys</u> <u>kempii</u>	Kemp's ridley	E	Caribbean
<u>Lepidochelys</u> <u>olivacea</u>	Olive ridley	T	Tropical circumglobal
<u>Caretta</u> <u>caretta</u>	Loggerhead	T	Tropical circumglobal
OTHER REPTILES			
<u>Cyclura</u> <u>pinquus</u>	Anegada Island ground iguana	E	Virgin Islands
<u>Cyclura</u> <u>stejnegeri</u>	Mona Island ground iguana	T	Puerto Rico
<u>Ameiva</u> <u>polops</u>	St. Croix ground lizard	E	St. Croix, Virgin Islands
<u>Eprcrates</u> <u>inornatus</u>	Puerto Rican boa	E	Puerto Rico
AMPHIBIANS			
<u>Eleutherodactylus</u> <u>jasperi</u>	Golden coqui	T	Puerto Rico
BIRDS			
<u>Pelecanus</u> <u>occidentalis</u>	Brown pelican	E	Caribbean, U.S. west coast, Gulf coast
<u>Puffinus</u> <u>puffinus</u> <u>newelli</u>	Newell's Manx shearwater	T	Hawaiian Islands
<u>Acrocephalus</u> <u>familiaris</u> <u>kingi</u>	Nihoa miller- bird	E	Nihoa, Hawaiian Islands

* E = Endangered

T = Threatened

TABLE 12.--Continued.

Scientific Name	Common Name	Status	Distribution
BIRDS			
<u>Psittirostra</u> <u>cantans</u> <u>cantans</u>	Laysan finch	E	Laysan, Hawaiian Islands
<u>Anas</u> <u>laysannensis</u>	Laysan duck	E	Laysan, Hawaiian Islands
<u>Anas</u> <u>wyvilliana</u>	Hawaiian duck	E	Hawaiian Islands
<u>Pterodroma</u> <u>phaeopygia</u> <u>sandwichensis</u>	Hawaiian dark-rumped petrel	E	Hawaiian Islands
<u>Fulica</u> <u>americana</u> <u>alai</u>	Hawaiian coot	E	Hawaiian Islands
<u>Himantopus</u> <u>himantopus</u> <u>knudseni</u>	Hawaiian stilt	E	Hawaiian Islands
<u>Gallinula</u> <u>chloropus</u> <u>sandvicensis</u>	Hawaiian gallinule	E	Hawaiian Islands
<u>Branta</u> <u>sandvicensis</u>	Hawaiian goose	E	Hawaiian Islands
<u>Caprimulgus</u> <u>noctitherus</u>	Puerto Rican Whip-poor-will	E	Puerto Rico
<u>Amazona vittata</u>	Puerto Rican Parrot	E*	Puerto Rico
<u>Columba inornata</u> <u>wetmorei</u>	Plain Pigeon	E	Puerto Rico
<u>Agelaius</u> <u>xanthomus</u>	Yellow-shouldered Blackbird	E	Puerto Rico
<u>Falcon</u> <u>peregrinus</u> <u>anatum</u>	American Peregrine Falcon	E	North American, Caribbean

* E = Endangered

T = Threatened

SUMMARY OF PERTINENT BIOLOGICAL CHARACTERISTICS OF POTENTIAL
OCEAN THERMAL ENERGY CONVERSION (OTEC) SITES
IN THE PACIFIC OCEAN

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August 1983

Southwest Fisheries Center Administrative Report H-83-13

I. INTRODUCTION

The oil crisis of 1973-74 sparked a movement among many oil-dependent nations of the world to look at alternative forms of energy to satisfy their energy needs. Particularly vulnerable were isolated island communities that relied heavily on imported oil for their energy needs. As oil grew progressively costly, island governments exerted greater effort to conserve and to look for other affordable sources of energy.

Among alternative sources considered suitable were direct solar radiation, wind, biomass, and ocean thermal energy. All are renewable and presumably nonpolluting compared with oil, coal, and nuclear energy.

Among them, the ocean offers a tremendous potential as an energy source. Ocean thermal energy conversion (OTEC), a technique for tapping incoming solar energy stored in the surface layers of tropical and subtropical oceans, is a promising technology that is particularly useful to a large number of island governments and developing nations. Because the ocean thermal energy resource lies primarily within the 20° latitudinal bands, developing countries that lie within or near these boundaries can exploit OTEC in their contiguous territorial seas.

This report synthesizes existing historical information that has pertinence to representative land-based and plant ship OTEC sites in the Pacific Ocean. It provides the basis for extrapolating environmental information to probable OTEC operating conditions so that the potential risk of such facilities to existing fisheries and other marine resources can be evaluated.

A. Overview

In 1 hour the world's oceans receive enough solar energy theoretically to meet its annual demand for fuel. Solar radiation is greatest just beneath the sun and decreases as we move away from that point (Gross 1972). Averaged over a year, the maximum amount of solar energy is absorbed in the low-latitude tropical region. The result is that the Earth receives most of its heat between lat. 40°N and 40°S, whereas there is a net loss in the high latitudes between 40° and 90° in both hemispheres. The heat transfer from low to high latitudes in the ocean and atmosphere functions as simple heat engines. The transformation of some of the ocean's heat energy into mechanical energy is in the form of waves, currents, and winds. A large proportion of the solar energy, however, is simply stored in the warm tropical waters. Tapping this stored energy with OTEC can produce electrical energy, which is currently produced by other fuel and technologies including oil, coal, nuclear power, and hydropower, as well as energy intensive products such as hydrogen, ammonia, and aluminum. An important by-product of some OTEC system design is fresh water.

The OTEC relies primarily on the temperature difference between the warm surface and cold deep waters of the oceans. Warm water drawn from the ocean's surface provides heat which is transferred through a heat exchanger to a working fluid. Enclosed in a partial vacuum, the working fluid is evaporated by the heat and the resulting high-pressure vapor drives a

turbine to produce electricity. Cold water is then pumped from the deep layers to condense the low-pressure vapor in a second heat exchanger. The working fluid is then pumped back and recycled.

B. Potential Areas

Although the ocean thermal resource needed for OTEC can be found year round in the tropics between lat. 20°N and 20°S , achieving maximum efficiency from an OTEC plant would require certain characteristics for optimal deployment. Among these are the bottom topography and profile, temperature difference between the warm surface and cold deep water, substrate, permanent water flow, currents (tidal, wind-driven, and inertial), mass transport by waves, climatic conditions, benthic properties, and chemical properties of the sea water.

1. Temperature and depth requirements

Site selection is very critical to the development of an OTEC plant. The magnitude of the temperature change (ΔT) between the warm surface layer and the cold deep layer must be sufficiently large to maintain power plant output and efficiency. An operational minimum ΔT of 19C° ¹ is essential (Haven 1981), and an annual minimum temperature difference of at least 20C° between surface and deep-ocean waters is necessary (Sullivan et al. 1981). The mixed layer not only must be sufficiently deep to ensure that the warm-water resource is available at the intake depth but also is a consideration in calculating the discharge depth at which recirculation is kept to a minimum.

The ocean thermal resource for OTEC is enormous even if only areas with ΔT of at least 19C° are considered (Yuen 1981). The depth requirement for a potential OTEC site will vary depending on the geographical location of the plant. For example, at Kahe Point, Oahu, the water at 500 m is about 18C° colder than surface water whereas at 1,000 m the water is colder than surface water by about $20\text{--}22\text{C}^{\circ}$. On the other hand, ΔT of 19C° can be maintained at only 457 m in waters off Guam.

Figures 1 and 2 show ΔT between the surface and 1,000 m for the world's oceans between lat. 40°N and 40°S (U.S. Department of Commerce 1980).

2. Economic resource zone boundaries

The 200-mile economic zones of countries in the Pacific Basin and around the rim are shown in Figure 3. Economic zones of adjacent countries within many parts of the South Pacific are not well established. Except where grazing plant ships would be operating in open water, it is not anticipated that boundary disputes will occur, because most plant designs under consideration involve shoreside facilities or nearshore towers.

C. Predicted Sites

Several sites in the Pacific have been studied for possible land-based OTEC facilities, including Keahole Point and Kahe Point in the Hawaiian

Islands, Cabras Island off Guam, Japan, Manila in the Philippines, the Republic of Nauru, Taiwan, Mexico, French Polynesia, and New Caledonia.

1. French Polynesia and New Caledonia

French Polynesia and New Caledonia are considered potential OTEC sites in the South Pacific (Yuen 1981). Results of a study by the Centre National pour l'Exploitation des Océans (CNEXO) indicated that an offshore plant of 3-15 MW is feasible in waters close to Tahiti. With costs about equal for both an open- and closed-cycle system,² CNEXO favors the former because of the added advantage of fresh-water production. A small-scale OTEC plant is also economically competitive with oil-fired plants in tropical islands (Marshand 1979, 1980).

2. Guam

The existence of ideal oceanographic conditions such as consistently warm surface water and a steep submarine slope close to shore makes OTEC a viable alternative for energy in Guam. Lassuy (1979), demonstrated a consistent annual mean ΔT difference of 23.4°C between the surface and depths of about 854-915 m near Cabras Island and Luminao Reef (Figure 4) and that this ΔT could be obtained only 1.75 km offshore from the Glass Breakwater at the western tip of Luminao Reef.

A review of the oceanographic information from Guam, showed that the temperature difference resource near Guam is unsurpassed among 10 other sites examined throughout the world (Wolff 1979a, Tables 1 and 2). Wolff found mean monthly surface temperatures consistently high year round, ranging between 27.7° and 29.2°C . Likewise, consistently large and stable ΔT values were available through the year; an annual average ΔT greater than 20°C is available at depths of slightly less than 500 m.

The major obstacle to OTEC development at Guam is the frequency of typhoons and tropical storms. Seismic activity in the Guam area also poses a threat to OTEC operations. Wolff added that ocean currents near Guam were generally moderate in strength and varied only slightly in direction.

3. Hawaiian Islands

Hawaii, which is located in the northern limit of the Pacific tropical water mass where the temperature difference between surface and deep water is sufficiently large to support OTEC operations, has a steady accessible thermal resource at or greater than 19°C (Haven 1981). Long-term surveys of physical oceanographic conditions and ocean bathymetry around Hawaii revealed that at a depth of 500 m, the waters were typically about 18°C colder than surface water whereas at 1,000 m, the ΔT values increased to $20-22^{\circ}\text{C}$. The maximum obtainable differences were 24°C at 500 m and 26°C at 1,000 m.

Haven reported that although the thermal profiles for most sites studied in Hawaiian waters showed very similar temperature gradients and seasonal shifts, long-term thermal measurements showed a substantial

surface temperature variation over time. For example, surface temperatures averaged only 22.8°C in 1930. A return to sea conditions responsible for this low temperature could have a disastrous impact on OTEC operations.

According to Haven, the appropriate annual mean temperatures for OTEC operations in Hawaii should be 25°C $\pm$ 1.2°C for surface waters and a constant temperature of 4.5°C at 800 m. These design temperatures should produce a usable thermal gradient of 19.2-21.7°C over the year.

Surface temperatures ranged from 24.7° to 27.1°C at Keahole Point (Bathen 1975). Below the mixed layer, which was 80-100 m thick, temperatures decreased rapidly for another 200 m and only slightly from 330 to 350 m. At 550 m, the temperature was 6.9°C; thus a ΔT of 18.8°C was possible at 550 m. Bathen noted that an annual thermal difference of 18-20°C was typical in the Keahole region. The minimum temperature difference at 610 m was 20.6°C in summer and 18.2°C in winter.

Currents ranged from 0.05 to 0.6 knot off Keahole and speeds of 0.1-0.3 knot were rather typical. The net surface transport was north to northeast in winter (November-May) and a north to south transport (tidal) was more apparent in late summer, although the net drift remained northerly.

Off Keahole, the nearshore slope is steep: It is 610 m deep about 0.8 nmi from shore. The maximum recorded wave height was 1.8 m with a period of 14 sec; however, waves were below 1.2 m about 97% of the time. Bathen predicted the maximum significant wave height for this location to be about 6 m.

Climatic conditions in the Keahole area were generally mild. Winds blew onshore during the day and offshore at night, and rarely exceeded 5 knots. During infrequent storms, wind speeds of 15-30 knots can be expected.

At Kahe Point on the western shore of Oahu, the 1,000-m contour is about 3.8 nmi from shore. The minimum ΔT observed at this site was 20.0°C whereas the maximum reached 22.8°C (Ocean Data System, Inc. (ODSI) 1977). Studies by Seckel (1955) and Maynard et al. (1975) indicate that a minimum of 914 m will be needed to obtain a ΔT of 19°C during winter when surface temperatures are colder. In summer, the temperature difference between the surface and 914 m ranged to 23.0°C.

The depth of the mixed layer at Kahe Point was 50 m in summer and 90 m in winter (ODSI 1977). The upper water column off Kahe exhibited what appeared to be some seasonal variation in current speed whereas in waters deeper than 350 m, there was no evidence of seasonal trend (Noda and Associates 1982). At 50 m, the monthly maximum current speed ranged from 52.7 cm/sec in August to 77.4 cm/sec in May (Noda 1981). Monthly mean values at this depth varied from 17.5 cm/sec in August to 27.2 cm/sec in March.

Currents are often strong off Kahe but could be highly variable (Bathen 1978). The net drift is rather consistent and moderate to strong

toward the south of Maili Point to Barbers Point from August to January when winds are less dominated by the northeast trades. In deep water, net drift is variable toward the shoreline from February to April and directly offshore from May to July.

Waves impinging on the Kahe area may be generated either from earthquakes (tsunami) or wind. An OTEC power transmission cable would require adequate tsunami protection through the coastal zone. Runup or vertical height change during a tsunami at both Kahe and Barbers Point was about 3.6 m during the 1946 tsunami that washed the shores of Oahu (Cox and Mink 1963; Dames & Moore 1970; Armstrong 1973).

In Hawaiian waters, there are a number of sites that satisfy criteria for both nearshore floating and shore-based OTEC power plants. Shupe (1982) identified several locations throughout the state that have some potential for OTEC systems, but reported that additional bathymetric and ocean current studies are needed to verify these sites as suitable. Based on his findings, these areas are:

- o Hawaii--Off Leleiwi Point southward to Cape Kumukahi and along the southeastern coast to Ka Lae, then northward along the southwestern and western coasts as far as Keahole Point.
- o Maui--Off Hana; also along the southeastern coast from about Kipahulu to Kiakeana Point.
- o Molokai--Off Makenalua Peninsula.
- o Oahu--Along the Waianae coast from Barbers Point to Kaena Point.
- o Kauai--Off the north shore between Hanalei and Kilauea Point; also along the eastern and southern coasts from Wailua to Waimea.

4. Japan

Although the Japanese islands are well north of lat. 20°N and outside the tropical zone where the ocean thermal resources can be found year round, they are strategically located, because the Kuroshio constantly brings a large amount of thermal energy in the form of warm surface water from the tropics.

Oceanographic studies indicate that the Pacific coast of Japan is bathed by the Kuroshio which brings sufficiently warm surface temperature (28°C) and has cold water that can be obtained from 790-m for the needed ΔT .

Homma et al. (1979) considered five sites for OTEC development off Japan. These were at Iriomote Island, Okinawa Island, Toyama Bay, Osumi Islands, and the Izu Peninsula. Data collected from four of the sites showed maximum wind velocity ranging from 39.6 to 78.6 m/sec, significant wave height varying between 8.5 and 15.0 m, and frequency of typhoons ranging from 21-40 times/year at Toyama to 41-60 times/year at Iriomote, Okinawa, and Osumi. They concluded from their studies that Osumi and

Toyama would be most suitable as representative sites for OTEC development in Japan.

Homma et al. reported that the temperature profile at Osumi was quite different from that at Toyama. At 500 m, the temperature at Osumi reached 9.18°C whereas at Toyama, it was 0.35°C . The optimum cold-water intake depth was determined to be 790 m at Osumi and 370 m at Toyama. Minimum and maximum mean surface temperatures 1,000 m off Osumi and Toyama are shown in Figure 5.

In addition to developing OTEC facilities to satisfy their own power needs, the Japanese are also vitally cognizant of the market in technology transfer, particularly along oil-dependent Pacific islands where ΔT 's are excellent all year long and deep cold water is available nearshore. In 1979, Tokyo Electric Power Services Company, Ltd. began work on a 100 kW "experimental confirmation" closed cycle plant sited on the island of Nauru. This plant was a research facility for testing heat exchangers (H. Pennington, DPED, pers. commun., September 15, 1982).

5. Manila, Philippine Islands

Historical oceanographic data indicate that in waters off Manila, Philippine Islands, an excellent thermal difference exists between surface and deep water to make OTEC development feasible (Wolff 1979b). Between lat. 14° - 16°N and long. 118° - 120°E off the west coast of Luzon, surface temperatures were high throughout the year and the lowest monthly mean was about 27.2°C . The monthly mean ΔT was 24.0°C at 1,000 m, and annual mean thermal difference was 20.0°C at 500 m. It was concluded from the study that the thermal difference at 500 m was sufficiently large and that the cold water pipe for the plant could be made relatively short.

Wolff found that the continental slope off the Philippines was steep and that the 1,000-m contour lay within 10 nmi off the shoreline around Luzon. The single most important obstacle to OTEC development was climatic conditions, that is, typhoons, high winds, and storms were a major problem in this area. In addition, seismic activity could create further concerns.

Water currents around the islands were generally moderate with some variation during the year. Also, the mixed layer appeared to be adequate throughout the year.

6. Mexico, west coast

A study of a site chosen for possible OTEC development off the west coast of Mexico showed that the temperature difference was more than adequate for potential use (Wolff 1979d). The site (between lat. 20° - 23°N and long. 105° - 110°W), had an annual mean ΔT of 20.0°C at 800 m and 20.9°C at 1,000 m. During March, the coldest month of the year, the mean ΔT was 17.2°C . Wolff reported that at 800 m, there was some variation in monthly mean temperature difference; however, this difference was adequate even in the coldest month (Tables 1 and 2).

The relatively shallow mixed layer in this area was persistent throughout the year. Surface currents were weak with some variation in the direction of the flow. Because of the existence of a large continental shelf, the distance from shore to the 1,000-m depth contour was relatively great although one bay nearby could supply cold deep water within 2.7 nmi from the site.

Storms could be a major problem in this area from May to November; sea conditions and swells were moderate and did not appear to be of major concern.

7. Pacific plant ship

A plant ship is a self-propelled surface platform which can cruise to areas where ΔT is greatest and storms less severe so that OTEC power can be used to produce a storable energy-intensive product or other commercial products such as ammonia, hydrogen, methyl alcohol, liquid natural gas, aluminum, alloys prepared in electric furnaces, semiconductor materials, and to refine manganese nodules (Avery 1980). Proximity to shore and power grids is not an important consideration for a plant ship compared with land-based or bottom-mounted plants. Furthermore, distance to shore is a minor consideration and there is no need for submarine cables to transmit electricity. Although information on bottom topography is not crucial, it is necessary that there be sufficient depth to provide the cold water needed.

The site examined for plant ship operation was located near the approximate limits of the North Equatorial Current and the Pacific Equatorial Countercurrent (between lat. 5° - 10° N and long. 90° - 95° W). Wolff (1979c) described this area as excellent for potential OTEC use. He found surface temperature consistently high, ranging from 26.5° to 28.5° C, and an annual mean ΔT greater than 20° C at a depth of 550 m or greater (Tables 1 and 2).

For the entire plant ship region studied, Wolff found bottom depths much greater than 1,500 m. The depth of the mixed layer was very shallow year round but also nearly nonexistent at times, indicating that a warm-water intake could be located (or positioned) very near the surface. Storms and high winds were not a major problem for this site partly as a result of its proximity to the Equator. Compared with other Pacific sites examined, mean surface currents were somewhat larger in magnitude. Wolff concluded that current shears may be troublesome in this area.

8. Taiwan

Like Japan, Taiwan is also situated within the influence of the Kuroshio, thus making it possible to consider OTEC. Along the east coast of Taiwan, the Kuroshio flows close by and the 1,000-m depth contour is relatively close to shore. Liang et al. (1980) found that the ΔT of 20° C occurred at about 500-550 m in May-October in waters off Hualien (Figure 6). The mixed layer off Taiwan was usually 20 m thick in the summer but as much as 60 m in the winter. Frequently, no mixed layer existed at other times of the year. Liang et al. concluded that the water off Taiwan was

highly stratified; therefore, they recommended that the warm-water intake for any OTEC plant be located near the sea surface. They further recommended that because of the hazards from a typhoon, any OTEC plant built in Taiwan should be a shelf-mounted facility.

In a second study, Liang et al. (1981) examined a site further south along the eastern and western coasts of southern Taiwan. Data were gathered for 6 months at a depth of 300 m off Hung-tzai (Figure 6). Their study demonstrated that by utilizing an existing nuclear power plant's discharged cooling water, which was about 10C° higher than ambient water, it would be possible to attain a ΔT of 21°-25°C. Other results indicated that the mixed layer is not detectable in summer and that the thermocline generally extended to 200 m. They concluded that from the standpoint of ocean engineering, Hung-tzai was ideal for a land-based OTEC plant coupled to a power plant.

II. PHYTOPLANKTON

Ranging in size from about 1 μ to 1 mm, marine phytoplankton include representatives of many algal groups. These free-floating algae build up protoplasm and food reserves directly from carbon dioxide and nutrient salts and form the base upon which the rest of the marine food chain depends (Newell and Newell 1963; Sullivan et al. 1981). Although most bacteria are heterotrophic, they are not included in the phytoplankton because of their ability to absorb organic nutrients directly from the external medium.

Because the effects of OTEC on the marine environment are likely to be seen initially in changes in the phytoplankton, due in part to the discharge of cold, nutrient-rich deep water into the photic zone, any shifts that occur in standing stock, community structure, or photosynthetic activity of the phytoplankton carry implications for the entire trophic community (Noda et al. 1981b).

The standing stock and primary productivity of phytoplankton are usually determined by assessing chlorophyll *a*, phaeopigments, adenosine triphosphate (ATP), and photosynthetic rate (Noda et al. 1981b). Chlorophyll *a* values are universally accepted as a measure of phytoplankton biomass whereas phaeopigment values, obtained in the process of adjusting the accuracy of chlorophyll *a* values, also provide physiological and ecological indices of community status. The ATP values give a measure of total biomass which embraces not only phytoplankton but also bacteria and microherbivores. Photosynthetic rate is essentially a measure of primary productivity and represents the primary input of chemical energy into the marine food web.

A. Open Ocean Sites

Because OTEC-1 experiments were carried out aboard the Ocean Energy Converter (OEC) anchored offshore in the Keahole Point area, data gathered from these experiments can be used to depict ecosystem functions at open ocean sites. The following discussion revolves around some of the results

obtained from these experiments and the results of the Deep Ocean Mining Environmental Study (DOMES) that are pertinent to this report.

1. Biomass, primary productivity levels, compensation depth

1.1 Biomass

Simply defined, biomass is the amount of living matter per unit of water surface or volume and is used as an index of standing stock. Typical units for standing stock measurements are $\mu\text{g/liter}$, mg/m^3 , g/m^2 , and kg/ha . Additionally, phytoplankton standing stock may be described as consisting of 10^6 cells/liter of a species, or being represented by a chlorophyll a concentration expressed as mg/m^3 (Parsons and Takahashi 1973).

In a study to evaluate the variability in physical, chemical, and biological parameters at an open ocean site off Keahole Point, Hawaii, at lat. $19^{\circ}55'\text{N}$ and long. $156^{\circ}10'\text{W}$ in waters 1,300-m deep (Figure 7), Noda et al. (1980) conducted six cruises (HOTEC-1 through HOTEC-6) to examine an OTEC benchmark site. They found a surface mixed layer of relatively low chlorophyll a concentrations, ranging between 0.03 and 0.18 mg/m^3 . As is typical of other oceanic water columns from many regions of the world's oceans, a subsurface chlorophyll maximum was also present below which values declined to negligible levels. Among the explanations offered for the presence of the deep chlorophyll maximum were:

- o Decrease in phytoplankton sinking rate.
- o Increase in cellular content of chlorophyll via adaptation to reduced light levels.

Noda et al. (1980) reported that the subsurface chlorophyll maximum was located between 64 and 94 m and ranged from 0.17 to 0.62 mg/m^3 (Figure 8). Temporal variability in phytoplankton stock was demonstrated by comparing the integrated levels. Within the mixed layer, integrated chlorophyll values were $1.93\text{--}10.30 \text{ mg/m}^2$ compared with $13.77\text{--}45.13 \text{ mg/m}^2$ for the entire upper 260 m. Noda et al. found no correlation between variations in the standing stock of phytoplankton and variations in any of the other parameters measured.

Phaeopigment values are usually of importance in adjusting chlorophyll measurements for possible contamination (Shuman and Lorenzen 1975). The phaeopigment profile at Keahole paralleled the shape of the chlorophyll profile; concentrations were usually one-third to one-half the chlorophyll levels, except in the region of the pigment maximum where phaeopigment concentrations increased to 80-90% of the chlorophyll levels (Bienfang 1977). Noda et al. (1980) found a similar distribution of phaeopigments where the vertical structure was similar to that of chlorophyll. Over six cruises, the shape of the vertical profile was similar; however, the phaeopigment levels varied widely from undetectable levels to 0.09 mg/m^3 within the mixed layer, from 0.05 to 0.45 mg/m^3 at the subsurface maximum level, and from 3.67 to 22.53 mg/m^3 integrated over the entire upper 260 m.

Noda et al. (1980) also noted that the depth of the phaeopigment maximum was at or below that of the chlorophyll maximum. They reasoned that this difference may be attributed to photo-oxidation of the light-labile phaeopigments and to phaeopigment production in a region where low light levels inhibit phaeopigment degradation and chlorophyll production.

Noda et al. (1980) also used ATP values as a total microbial biomass indicator for offshore waters off Keahole Point. They found that the ATP values generally decreased with depth. In the surface layers (0-100 m), values were highly variable ranging from 2.37 to 52.72 $\mu\text{g}/\text{m}^3$. They found no indication of a subsurface maximum as was apparent for chlorophyll a and phaeopigment concentrations. Depth-integrated ATP values varied from 0.56 to 5.72 mg/m^2 over 12 hydrocasts. The average over six cruises was 3.00 ± 1.78 (s.d.) mg/m^2 .

The ATP method, one of several biochemical techniques used to estimate microbial biomass, measures the biomass of total microplankton including phytoplankton. Sorokin (1981) has reported that ATP values may be difficult to interpret and may exceed the real microbial biomass by 1.5 to 4.0 times. Nevertheless, empirical correlations have been found for some oceanic habitat thereby making the method useful.

Noda et al. (1980) also used the production/biomass (P/B) ratio expressed as $\text{mg carbon}/\text{mg chlorophyll a}/\text{h}$ (Bienfang and Gundersen 1977) as an indicator of the specific rate of activity of each biomass unit. Primary productivity values represent the rate at which phytoplankton are performing work or putting energy into the trophic system whereas chlorophyll a values represent the component of the population performing that work. For data from six cruises P/B ratios varied from 0 to 8.31 $\text{mgC}/\text{mg chlorophyll a}/\text{h}$. Noda et al. found that the P/B ratio varied vertically and temporally. Vertically, P/B ratios from all cruises rapidly declined with depth which indicated a diminishing availability of light for photosynthesis. Temporally, the range of P/B ratios over the water column for each of the six cruises were as follows: 0.72-4.57; 0-2.80; 0-2.27; 0.03-0.52; 0.32-8.35; and 0-1.11 $\text{mgC}/\text{mg chlorophyll a}/\text{h}$. Almost all the values, particularly those from near surface samples demonstrated strong nutrient impoverishment.

In a study in the DOMES area of the tropical Pacific (Figure 9), El-Sayed and Taguchi (1979) found that the water in this region (lat. 5° - 20°N and long. 128° - 155°W) was characterized by low chlorophyll a values, a condition normally expected for oligotrophic tropical and subtropical oceanic waters. The surface chlorophyll a values averaged $0.117 \text{ mg}/\text{m}^3$ whereas the value integrated through the water column (to the bottom of the euphotic zone) averaged only $19.6 \text{ mg}/\text{m}^2$. Also, a subsurface chlorophyll a maximum layer (CML) was characteristic of the area studied and the CML was found deeper in summer ($69 \pm 24 \text{ m}$) than in winter ($54 \pm 30 \text{ m}$). The chlorophyll a value was high below the euphotic zone and contributed about 20% of the chlorophyll in the water column in summer and winter. The data suggested that the CML results either from grazing by zooplankters or from slower growth of larger phytoplankton cells (Figures 10 and 11).

El-Sayed and Taguchi reported that in summer the CML was either in the middle or at the bottom of the pycnocline and corresponded to about 10% of the surface light level whereas in winter this layer occurred at either the top or in the middle of the pycnocline and corresponded to about 20% of the surface light level. They found a close relationship between the depth of the CML and the nutricline, particularly that of nitrate. Below the maximum, there was a general decline in the concentration of chlorophyll.

1.2 Primary production levels

The photic zone off Keahole extends to about 125 m. Primary productivity rates were somewhat higher in shallow levels but surprisingly uniform throughout the photic zone (Noda et al. 1980, Figure 12). The significant feature of the data was the wide variation among the six cruises. Covariance analysis gave a statistically significant correlation. The average depth-integrated phaeopigment values and the depth-integrated primary productivity value were significantly correlated ($r = 0.92$; d.f. = 4; $P < 0.01$) whereas the depth-integrated chlorophyll and the integrated primary productivity values showed no significant correlation. Noda et al. concluded that the input rate of regenerated nutrients has a strong positive effect on the rates of primary production off Keahole. Total primary productivity over six cruises ranged from 0.72 to 18.70 $\text{mgC/m}^2/\text{h}$ or 8.64–224.40 $\text{mgC/m}^2/\text{day}$. Annual primary production varied from 12.04 to 101.11 $\text{gC/m}^2/\text{yr}$. Wide natural variation in primary productivity rates is a typical feature of the Keahole Point marine environment.

Compared with other net primary productivity values obtained from different areas of the world's ocean, the area off Keahole is sometimes as productive as the Sargasso Sea, which has a net primary production of 70–145 $\text{gC/m}^2/\text{yr}$, but far less productive than the Gulf of Guinea (365 $\text{gC/m}^2/\text{yr}$) and Long Island Sound (190 $\text{gC/m}^2/\text{yr}$) (Dunbar 1975). The normal rate of primary production in oceanic waters has been estimated by Riley (1970) to vary from 50 to 150 $\text{gC/m}^2/\text{yr}$ (150 to 300 $\text{g dry weight/m}^2/\text{yr}$).

Primary productivity in the DOMES area was generally low (El-Sayed and Taguchi 1979). These results agreed quite well with those of other studies in the same or adjacent area. Primary production values at the surface in summer averaged 1.5 $\text{mgC/m}^3/\text{day}$ whereas in winter it reached 2.7 $\text{mgC/m}^3/\text{day}$. The daily primary production in the euphotic zone was 120 $\text{mgC/m}^2/\text{day}$ in summer and 144 $\text{mgC/m}^2/\text{day}$ in winter. Maximum primary production was at 50% of the surface light level in the summer but was found at or near the surface in winter. In summer and winter, nanoplankton ($<20 \mu\text{m}$) contribution to primary production averaged 77%. Nanoplankton contribution to total primary production was lower in winter (about 63%) than in summer (83.3%). Phytoplankton production below the euphotic zone, at an average depth of 104 m, contributed about 5% of the total production in the water column. Unlike the phytoplankton standing crop, primary production was not controlled by the depth of the mixed layer.

El-Sayed and Taguchi (1979) also found significant spatial and seasonal variation in the phytoplankton standing crop and primary production. They concluded that whereas the phytoplankton standing crop is likely to be controlled by the depth of the mixed layer, primary production

was independent of it. Phytoplankton and zooplankton data suggested that the DOMES area is at a near steady state for an interval of a few days. This indicated that the feeding of the zooplankton on phytoplankton apparently balanced production by phytoplankton.

1.3 Compensation depth

The number of quanta required for the evolution of one molecule of oxygen by green plants has been shown to vary from 3 to 10 quanta/O₂ (Forti 1966). The wide variation in these measurements results from not only difficulty in the experimental methodology but also because respiration occurs simultaneously with photosynthesis. Under conditions of light saturation, the rate of photosynthesis is up to 20 times higher than the rate of respiration; however, at lower light intensity deeper in the water column, a depth is reached where light intensity is just sufficient to bring about a balance between the oxygen produced through photosynthesis and that consumed through respiration. The depth at which this balance occurs is called the compensation depth.

The compensation depth in ocean ecosystem is, therefore, the division between an upper euphotic or trophogenic zone where primary production is possible, and a lower zone where biological activity is confined to consumption of imported energy (Westlake 1966). During highly productive periods, the compensation depth is approximately the same as the depth of the mixed layer. The effective biomass of primary producers includes the populations above and below the thermocline. If the compensation depth is above the thermocline, phytoplankton may sometimes be near the surface and are capable of positive net photosynthesis; however, at greater depth, they can only respire but be still available as a food source. In such a situation, the gross productivity per unit area will not be affected, but net productivity will be reduced because of the respiring population below the compensation depth. Compensation depth can vary with season, illumination, turbidity, and other factors.

Increases in phytoplankton biomass and assimilation rate can occur only in water layers which receive a minimum illumination of 400 lx (Moiseev 1969). Below this level, photosynthesis and proliferation cease and phytoplankton perish. In the summer compensation depth, has been estimated to be less than 50-100 m in the North and South Pacific about 80-120 m in the equatorial Pacific, and about 100-140 m in the subtropical regions.

Compensation depth can be approximated in field work as the depth at which light is attenuated to 1% of the surface radiation and can be estimated with a bathyphotometer or doubling the depth of the Secchi-disk visibility (Parsons and Takahashi 1973). Below the compensation depth, there is no net photosynthesis. The photic zone was 125 m at Keahole Point and 145 m at Kahe Point, which is characteristic of clear-blue ocean waters (Noda et al. 1980, 1981b).

1.4 Operational and post-operational results

Baseline data for an open ocean site are available for the operational phase of OTEC-1 and the post-operational phase. Results of these studies are summarized in the following section.

Biomass

To evaluate the effects on the environment during operational and post-operational phases of an OTEC facility, Noda et al. (1981a) carried out two special sampling cruises at the OTEC-1 site off Keahole Point. The first cruise in January 1981 (HOTEK-11) monitored the environment during the operational phase of OTEC-1 and the second cruise in April 1981 (HOTEK-12) sampled the area during the post-operational phase.

During the operational phase chlorophyll maximum values were significantly lower than those obtained during the benchmark survey in October 1978-December 1979. Furthermore, the maximum was not only deeper than observed previously but also significantly deeper at the OTEC-1 platform and downstream of the platform than at the control station. The depth-integrated chlorophyll value at the platform was 14% higher and 65% higher downstream of the platform than at the control.

Noda et al. (1981a) also found that maximum phaeopigment concentrations at subsurface levels exceeded values described earlier and were higher at the platform and downstream than at the control station. The depths of the phaeopigment maxima were significantly deeper at the platform and downstream than they were at the control station or when compared with the benchmark data. Also, significantly lower depth-integrated phaeopigment values were found at the platform and downstream than at the control.

Vertical profiles of in vivo fluorescence, measured to about 110 m, supported the vertical distribution pattern observed in the hydrocast data and showed an increase in chlorophyll at a shallower depth at the control station, which suggested that there were differences in the distribution of chlorophyll at the three stations.

Depth-integrated ATP values fell within the range of the historical data but they were significantly higher by 64% at the downstream station than at the control (Noda et al. 1981a). These results were in good agreement with the chlorophyll data from HOTEK-11.

Noda et al. (1981a) compared the results obtained from Site 1, a control station, and Site 2, which was representative of the OTEC-1 location, and found that the overall chlorophyll values showed similar ranges and patterns of distribution in the water column at Sites 1 and 2. Depth-integrated chlorophyll a values and depth-integrated phaeopigment levels were also very similar and not significantly different between sites.

The ATP concentrations ranged from 3.98 to 49.79 ng/liter overall and the highest value occurred at 70 m or just above the depth of the chlorophyll maximum at Site 1 but not at Site 2. However, because the

distribution pattern of ATP with depth at either site revealed the systematic development of a subsurface maximum, the absence of one is rather typical of the vertical pattern of ATP. Total microbial biomass and the mean depth-integrated ATP values showed similar levels at both sites.

Primary productivity levels

Of considerable interest are the primary productivity data. Photosynthetic rates were significantly higher at Site 2 near the OTEC-1 mooring buoy than at the control station (Noda et al. 1981a). Depth-integrated primary production averaged $14.53 \pm 0.86 \text{ mgC/m}^2/\text{h}$ at Site 1 whereas at Site 2, the average was $28.66 \pm 3.14 \text{ mgC/m}^2/\text{h}$. The coefficients of variation for the two sets of data were 0.03 and 0.11, respectively, indicating good precision for the average estimates derived for both sites.

Noda et al. also compared their results from HOTEK-12 with those from the benchmark cruises. They found that data from the control station during HOTEK-12 fell within the range of primary productivity rates from the benchmark cruises but data from near OTEC-1 fell outside. Statistical tests confirmed that Site 2 had significantly higher primary productivity than was typical for the area. Phytoplankton biomass (chlorophyll *a*) and total microbial biomass (ATP), however, showed no statistical difference at Sites 1 and 2. Noda et al., therefore, concluded that although primary productivity was significantly different between Sites 1 and 2, and between Site 2 and the benchmark data, it appeared that the changes in the rate of photosynthetic activity, rather than differences in the standing stock, were the primary motivators for the higher productivity.

Vertical distributions of cell density at the two sites during HOTEK-12 were dissimilar, but this was attributed to the naturally large variability and the restricted number of analysis (Noda et al. 1981a). The data, however, did provide a synoptic picture of the composition of the primary trophic level. Numerically, the concentrations were higher for the large and small cells, but Noda et al. attributed the differences between cruises HOTEK-11 and HOTEK-12 to sample collection and preparation procedures and not to actual changes in size structure.

Compensation depth

During the operation phase of OTEC-1, the extinction coefficient for light was $0.0325/\text{m}$, thus describing the floor of the photic zone at 128.5 m (Noda et al. 1981a). No significant difference was found in the primary productivity rates among the three stations occupied during HOTEK-11, but similarities were found between the rates calculated from HOTEK-11 and those observed during the benchmark survey.

Vertical profiles of *in vivo* fluorescence were similar at both sites (Noda et al. 1981a). Both traces showed a surface layer, 50-60 m thick of relatively uniform signal from the fluorometer. Subsurface maxima were between 80 and 100 m. Vertical profiles of submarine light, made to a depth of 90 m at both sites, showed that the extinction coefficient was $-0.0346/\text{m}$ at Site 1, whereas it was $-0.030/\text{m}$ at Site 2. The time-integrated quantum flux during the incubation periods (carbon fixation

experiments) was 12.0×10^{20} quanta/cm² in 8.75 h at Sites 1 whereas it was 7.80×10^{20} quanta/cm² in 6.5 h at Site 2. Noda et al. concluded that the average light field on the 2 days of sampling was very similar with only a 12% difference on a per-hour basis.

1.5 Plume survey

Noda et al. (1981c) carried out a plume survey using the OTEC-1 system aboard the OEC to (1) locate and map the physical extent of the thermal plume, both vertically and horizontally, (2) determine the dilution of the discharging effluent with ambient water as a function of location, (3) measure dissolved oxygen, salinity, and nutrients, and (4) measure ATP, chlorophyll a, phaeopigments, and zooplankton volumes.

The OTEC-1 system was designed with a mixed-water discharge 1.8 m in diameter directed downward just below the bottom of the hull at a depth of about 8 m. Discharge rates were about 9.8 m³/min which resulted in an exit velocity of 3.8 m/sec.

Data on several characteristics of the plume can be found in Noda et al. (1981c). They found that there were no significant differences between the chlorophyll, phaeopigment, and phaeopigment/chlorophyll (P/C) ratios in the plume and at a control station located at a depth of 25 m. Total microbial biomass (ATP), however, was significantly lower in the plume than at the control station, and the mean was only 61% of the control mean. Analysis of differences in pigments at each depth showed no significant difference between the plume and the control station.

By chi-square analysis, Noda et al. (1981c) also demonstrated that the frequency of lower ATP and chlorophyll values in the plume at various depths did not differ significantly from what would be expected by random chance and that there was a significantly higher frequency of phaeopigment and P/C ratios in the plume than at the control station.

2. Community composition

Specific information on phytoplankton community composition is available from water samples collected during the DOMES survey. Fryxell et al. (1979) classified these waters as oligotrophic but rich in the number of species present.

Ocean species of phytoplankton tend to be widely distributed. Fryxell et al. observed that half of the diatoms and about 57% of the dinoflagellates found in the DOMES area also occurred in the Mozambique Channel as reported by Sournia (1970). Semina (1974) listed over 1,000 taxa of phytoplankton from the Pacific. Table 3, which shows the number of species found from other studies together with those by Semina (1974), illustrates the large number of taxa occurring in the Pacific. Most are involved in primary production.

The 10 most abundant taxa found in the DOMES samples by Fryxell et al. are shown in Table 4. The flagellate and monad groups are combined and

shown as a single category; this group was by far the most abundant. The Gymnodiniaceae included all the dinoflagellates with nonrigid thecae that "round up" when preserved and several species were most likely included. "Yellow cells" include resting or reproducing cells full of storage material but with little morphological details that can be used to distinguish them.

Among the coccolithophores, Gephyrocapsa huxleyi (= Coccolithus huxleyi) was the most abundant, contributing nearly 60% of the total coccolithophorid cells and was also the most abundant species in the chlorophyll a maximum layer. It was increasingly dominant among coccolithophore species at all depths from about lat. 30°N to higher latitudes; in fact, it was practically the only coccolithophore present north of lat. 40°N to subarctic waters (Okada and Honjo 1973). Gephyrocapsa huxleyi also constituted from 25 to 50% of the coccolithophores in the zone described by Okada and Honjo as the "equatorial north."

Species of phytoplankton that occurred in samples from every station included two diatoms, three taxa of dinoflagellates, two coccolithophores, and two unidentified taxa. Taxa found at or below the chlorophyll a maximum layer included 31 diatoms, 19 dinoflagellates, and 9 coccolithophores (Fryxell et al. 1979).

Most of the species that occurred below the euphotic zone were found in small numbers and Fryxell et al. regarded them as "rare species" rather than truly "shade flora." They concluded that coccolithophores are an important group in the ecosystem of tropical and subtropical waters. They occur in roughly the same numbers as diatoms and dinoflagellates but most are small.

At Keahole, a substantial proportion of the phytoplankton biomass consisted of very small-celled organisms, usually less than 5 μm (Noda et al. 1980). Because these organisms are a characteristic feature of oligotrophic waters and potentially responsive to nutrient enrichment, Noda et al. (1981a) conducted detailed analysis of these organisms during HOTE-11. Size structure analysis showed that most of the phytoplankton biomass was in the <5 μm fraction. The fraction of chlorophyll biomass in the <5 μm fraction was significantly lower at the downstream station than at the control.

In the >5 μm fraction, the total cell volume at the control station was significantly higher than that at either the platform or downstream. Furthermore, in terms of cell density, the groups could be ranked in order of importance as: flagellates, dinoflagellates, diatoms, coccolithophores, and in terms of cell volumes, dinoflagellates, flagellates, diatoms, coccolithophores.

At the generic and specific levels, Noda et al. found that dinoflagellates were the largest and most conspicuous element of the phytoplankton community off Keahole Point. Large species such as Ceratium pentagonium, C. declinatum, C. teres, and C. schranbii, were seen in almost all samples whereas C. furen and C. fusus occurred only occasionally. The

genera of dinoflagellates observed included Oxytoxum, Gonyaulax, Peridinium, Amphidinium, Ornithocircus, Gymnodinium, Podolampas, Pyrocystus, Gyrodinium, and Dinophysis.

Noda et al. (1981a) also frequently encountered dinoflagellate cysts in the samples. Numerically, small dinoflagellates were important including Prorocentrum sp., Peridinium sp., Amphidinium sp., Gyrodinium sp., Gymnodinium sp., and Oxytoxum sp. Among the important centric diatoms in terms of cell volume were Coscinodiscus, Rhizosolanis, Licomorpha, Hemiaulus, Leptocylinndrus, Planktoniella, and Acinopticus. Small pennates most predominant numerically included Navicula, Nitzschia, and Gyrosigma. Coccolithophores included Discophaera tubifer, which was found in nearly every sample, and other genera including Emiliamaia, Gephyrocapsa, and numerous others. Flagellates in the samples were represented by Cryptophyceae, Chrysophyceae, Haptophyceae, and Choanoflagellata.

Johnson and Horne (1979), in their study of phytoplankton and biomass distribution at potential OTEC sites, reported that in Hawaii the net phytoplankton population was diverse including 76 identified species. In terms of numerical abundance, four species of pennate diatoms predominated including Dactyliosolen mediterraneus, Nitzschia closterium, Navicula sp., an unidentified athecate dinoflagellates.

All species and groups identified from Hawaiian waters were ranked (Table 5).

3. Seasonal variation

Differences in phytoplankton quantities are caused in part by differences in the reproductive rate of algae and in the grazing activity of zooplankton. Cushing (1981) reported that in temperate waters, the seasonal production of algae may be considered as a wave of high amplitude lasting 6-12 weeks which later subsides to much lower levels. In subtropical and tropical seas, however, the seasonal differences are much less pronounced. The exceptions are, of course, the upwelling areas where cycles analogous to those in temperate seas occur.

In the DOMES study area, chlorophyll *a* values averaged 0.063 mg/m³ in summer and 0.17 mg/m³ in winter (El-Sayed and Taguchi 1979). In the euphotic zone, the average value was only 9.8 mg/m² in the winter. Seasonal variations in other values were also found and these were discussed in earlier sections.

El-Sayed and Taguchi also found the CML at a depth of about 10% (summer) and 20% (winter) surface light level. Concentration in the chlorophyll maximum exceeded surface values by a factor of 3.6 ± 1.9 in summer and by 1.8 ± 0.8 in winter. At the CML, the proportion of chlorophyll *a* to total pigments (chlorophyll *a* plus phaeopigments) was lower (0.44 ± 0.06) in summer than in winter (0.56 ± 0.13).

B. Differences at Island Sites

Data collected during surveys conducted at Kahe Point are useful in examining differences in biological parameters between open ocean (Keahole and DOMES) sites and nearshore island sites. The Kahe Point surveys are particularly useful because not only has the site been selected for an OTEC pilot plant but also because much of the environmental surveys were completed before the construction of Hawaiian Electric's oil-fired generating plant at Kahe Point. Also, the location has been surveyed extensively during the O'OTEC cruises (Noda et al. 1981b; Noda and Associates 1982).

1. Kahe Point

In a study to obtain baseline data from waters off Kahe Point, Noda et al. (1981b) carried out a shipboard measurement program from May 1980 to May 1981. Bimonthly cruises were made to the following two O'OTEC benchmark sites off Kahe Point:

- o Site 1, at lat. $21^{\circ}19.5'N$ and long. $158^{\circ}12.5'W$, approximately 4.9 nmi west-southwest of Kahe Point (Figure 13).
- o Site 2, about 4.7 nmi west-southwest of Maili Point, at lat. $21^{\circ}23.5'N$ and long. $158^{\circ}15.5'W$.

Biomass

Based on results of six cruises, Noda et al. (1981b) reported that in the Kahe environment, there is a deep CML which is characteristic of many other oceanic systems and which represents an important facet of phytoplankton ecology. In time and space, the chlorophyll maximum remained about the same in vertical position (86 m) as well as in concentration (average = $0.27 \mu\text{g/liter}$). This layer accounted for 77% of the chlorophyll biomass in the photic zone. About 60-80% of the cells were in the $<3 \mu\text{m}$ size fraction. Pigment levels were low and uniform down to 44 m, and averaged $19.90 \pm 2.31 \text{ mg chlorophyll } a/\text{m}^2$ and $18.69 \pm 5.34 \text{ mg phaeopigments}/\text{m}^2$ over the year. Pigments also showed considerable uniformity over time except at both stations in August 1980 and at Station 1 in October 1980.

Primary production

The average annual primary production for the Kahe area was $60.4 \pm 15.6 \text{ gC}/\text{m}^2/\text{yr}$, a value similar to those for other subtropical gyre waters (Eppley et al. 1973; Gilmartin and Revelante 1974; Gundersen et al. 1976; Bienfang and Gundersen 1977; Sharp et al. 1980; Bienfang and Szyper 1982). The ratio of productivity to biomass, which is useful as a relative index of specific rates of photosynthesis, showed that the characteristic feature of the Kahe system is persistent nutrient limitation and that phytoplankton in the area are growing slowly. Noda et al. also observed a temporal pattern to the P/B ratios which paralleled that of photosynthesis. In the light-saturated layer, they found low P/B ratios from May to December and

generally higher ratios from January to May, which suggested a relaxation in the degree of nutrient impoverishment.

The results also indicated that photosynthesis in the light-saturated layer accounted for only 30% of the total production. Temporal variability, according to the authors, was due to changes in the activity of populations found in the light-limited layer. There was a highly significant positive correlation between fraction of production taking place below 44 m and that in the total water column (Noda et al. 1981b).

To determine which of the various processes influenced production in the light-limited layer, Noda et al. examined different variables but could not identify any which had a consistent seasonal pattern that would provide an explanation. They did, however, find that the temporal pattern of primary productivity had a general correspondence with local wind patterns, that is, during December-April when productivity was highest, the frequency of northeast, east, and southeast trades was lowest. Primary production was lowest from May to November, slightly higher from December through March, then low once again in May. The coupling between wind activity and ocean circulation, however, remains undelineated. The circulation off Kahe suggests that upwelling occurs during eddy formation, but it is insufficient in strength and duration to significantly affect the sea surface. It is reasonable to assume, however, that the lower regions of the photic zone are affected.

Compensation depth

The calculated depth of the 1% light level off Kahe Point ranged from 142 to 150 m and averaged 146 m (Noda et al. 1981b). The compensation depth at Kahe, therefore, is not dissimilar from the results obtained by Gundersen et al. (1976), who calculated the photic zone (defined according to the 1% light level) at Station B at 140 m in the Kealahiki Channel (between the Islands of Lanai and Kahoolawe at lat. 20°41'N and long. 156°55'W).

Community composition

Throughout the photic zone extending down to 145 m, 65% of the microbial biomass in the Kahe environment is represented by organisms in the $\leq 3 \mu\text{m}$ size fraction (Noda et al. 1981b). Takahashi and Bienfang³ reported that the vertical distribution of picoplankton is not influenced by sinking, thus reinforcing its dominance in a nutrient-limited environment. In addition, the picoplankton's potential for ammonium uptake at low levels favors its success in a substrate (light or nutrient) limited system. Takahashi and Bienfang found that the $\leq 3 \mu\text{m}$ fraction assimilates ammonium at rates 75% faster than those for the large 3-20 μm fraction. Thus, in the CML the picoplankton can take advantage of higher nutrient supply without being subjected to the hazards of sinking and therefore, being transported to light-deficient depths where photosynthesis is absent.

Noda et al. (1981b) suggested that the dominance of picoplankton off Kahe may be related to the prevailing nutrient field. Modest climatic fluctuations in the Kahe area produces thermal stratification which

persists thus restricting vertical input from deep nutrient-rich water. This produces an environment driven by regenerated nutrients and results in a condition characterized by numerous, small nutrient inputs, low ambient concentrations, and an importance of reduced forms of nitrogen.

Seasonal variations

Noda et al. (1981b) found considerable uniformity in pigment levels over time at Kahe Point, but there were exceptions particularly when large divergences occurred at both sites during August 1980 and at Site 1 in October 1980. The ATP values were highest in August-January but displayed a relatively even pattern the remainder of the year. Photosynthetic rates showed a consistent upward trend from low values in May-November 1980, increasing levels through March 1981, and slightly lower values to May 1981. Temporal variations were usually significant. Noda et al. concluded that although photosynthetic rates showed a significant increase during the second half of the survey period, the biomass parameters showed little regularity and unlike the photosynthetic rate no significant changes occurred. They reported that it was not clear whether any ecological significance can be attached to temporal variability of the biomass parameter.

Because two scales of spatial variability occurred during the Kahe survey, each was addressed by Noda et al. (1981b). Cast-to-cast differences were examined for small-scale spatial variability arising from the ship's drift during sampling; the average distance between hydrocasts was 0.9 km. Station-to-station differences were termed large-scale spatial variability and represented an average of 9 km on the horizontal scale.

The results clearly indicated that large-scale spatial differences in biomass parameters were not great. Noda et al. noted that although comparison of time-averaged values of the various parameters may indicate station-to-station differences since values at one station may exceed those at the other rather consistently, the differences between the means were not significant.

In nearly all the comparisons for photosynthesis, however, Noda et al. found that the Station 2 mean was higher than that for Station 11 and the absolute difference averaged $5.26 \text{ mgC/m}^2/\text{h}$ over the year of the study. This translated into 47% higher photosynthetic rate at Station 2. Thus, although absolute values of the station-to-station differences were not large in comparison with temporal variations observed earlier, the ability to measure differences between station may prove useful in future monitoring programs which assess the areal extent of impact to biological productivity resulting from the operation of an OTEC plant at Kahe. Noda et al. concluded that because large-scale spatial differences were not pronounced, small-scale differences were even less important.

Criteria standards for the Kahe environment

From the baseline data collected for the Kahe environment, Noda et al. (1981b) calculated the natural range of phytoplankton density, expressed as the 95% confidence limits for the depth-integrated data (Table 6). Also,

based on the given analytical capability and observed temporal and spatial variabilities at Kahe, they used the analysis of variance data to determine criteria for detecting significant environmental changes. They reasoned that the detection of significant differences between two measurements depends on precise measurements of the level below it; for example, analytical precision depends on precise measurements to detect any subsample variation. Table 7 gives the criteria for detecting significant ($P = 0.05$) differences for each parameter and for each level under examination.

2. Differences between the Keahole and Kahe environments

Noda et al. (1981b) compared the two oligotrophic Hawaiian ecosystems surveyed during the HOTEK and O'OTEC programs. Table 8 gives the values of the phytoplankton parameters off Keahole and Kahe Points; Table 9 summarizes the conclusions drawn by Noda et al. with respect to the various parameters compared.

Noda et al. suggested that differences in the nature and magnitude of temporal variations between the Kahe and Keahole environments may be related to the physical environments. The Keahole system, which is

adjacent to the deep Alenuihaha Channel over which wind strength increases due to the Venturi effects caused by high mountains, is exposed to large, rapid fluctuations in wind force, wave height, and water movement. Variability in these processes is thought to produce the complex biological systems that were observed in the environment. In contrast, Kahe is exposed to less intense winds that blow over the Kauai Channel. Because wind intensity is associated with divergence and upwelling, it is reasonable to expect that these processes are less intense off Kahe than off Keahole. The isolation of the Kahe system from severe weather and intense wave action results in less variability of the physical components and more gradual and systematic temporal cycles in the biological components.

3. Response of phytoplankton to nutrient enrichment

In subtropical regions where thermal stratification results from the absence of pronounced seasonal climatic variation, the nutrient-poor surface waters are isolated from the nutrient-rich deep waters.

Two processes govern the productivity of the ecosystem in the mixed layer--the availability of inorganic nutrients such as nitrates and phosphates and the availability of light. With increasing depth, light intensity decreases logarithmically to about 1% of the surface intensity. The relative availability of light and nutrients creates a transition from the nutrient-poor surface layer to the light-limited deep layer. Below the transition zone, light energy is too low for phytoplankton to occur (Yentsch 1966).

The amount of light in the euphotic zone is dictated by geography, season, time of day, the surface, and the transparency of sea water (Yentsch 1966). Light penetration is reduced if the ocean surface is

disturbed by wind action. Likewise, water transparency is reduced by the introduction of inorganic and organic suspended particles. Water itself can modify the wave lengths which penetrate it.

Because OTEC introduces large quantities of nutrient-rich deep water into a nutrient-poor surface layer at a rapid rate, unlike natural oceanic and coastal upwellings which are diffuse and slower, it is expected that biostimulation of phytoplankton will occur in the affected areas. For example, water drawn from 910 m will be high in nitrates and phosphates but low in oxygen and pH indicating elevated inorganic carbon concentrations ([Hawaii.] Department of Planning and Economic Development (DPED) 1980). When this deep water is finally discharged as effluent into the normally nutrient poor surface water, biostimulation should increase the rate of primary production several fold, provided that there is sufficient time for substantial photosynthesis to occur before the effluent sinks to a depth where the surrounding water is of the same density.

At sites approximately 12 nmi northwest of Keahole Point and also 6 nmi west of Kahe Point, Bienfang and Szyper (1982) performed nutrient enrichment experiments on water collected from nine target depths--2, 10, 30, 50, 70, 90, 110, 130, and 150 m. Their analysis demonstrated that deep-water enrichment produced immediate biostimulation of phytoplankton activity, and the degree of response was dependent on light availability with depth. The data also indicated that in the photic zone, the additive effect as a result of deep-water addition ranged from 1.23 to 5.47 mgC/m²/h representing increases of 9.3 to 149.0% over natural levels.

Bienfang and Szyper also found that short-term increases in carbon fixation caused by nutrient enrichment within the light-saturated layer represented an alleviation of the strongly nutrient-limited conditions. They concluded that all the additional nutrients supplied were probably not exhausted during the 11 hours of incubation and attributed this phenomenon, together with the inherent response capabilities of the phytoplankton population, as having influenced the degree of biostimulation.

Biostimulation, which was depth dependent and related to availability of light, was not present in the deepest samples collected at 100 m or deeper. Bienfang and Szyper attributed this lack of biostimulation to ambient nutrient concentrations in the water column which increased below 90 m, thus making excess nutrients superfluous. They also reported that there was a range of depths in which ambient nutrients were low and yet addition of deep-water nutrients did not induce biostimulation. These depths are below those of K_L light levels, but well above the depths where ambient nutrients began to increase (Table 10).

Low ambient nutrient level in the transition zone, where the upper limits ranged between 24 and 61 m and lower limit was around 90 m, indicates phytoplankton uptake paralleling the rates of nutrient supply (Bienfang and Szyper 1982). This suggested that, together with the low P/B ratios, photosynthesis in this layer was limited, at least partly, by nutrient availability. Furthermore, lack of response to deepwater nutrient addition suggested that light availability also influenced photosynthesis in this zone.

Evidently, information on the lower region of the transition zone is critical to the understanding of oceanic phytoplankton dynamics. Despite light limitations at this depth, the plant cells apparently utilize the available light rather efficiently thus attaining more than 60% of the theoretical maximum quantum yield in carbon fixation in the CML. The maximum absolute carbon fixation rate was at a depth of 70 m in oceanic waters off Oahu (Bienfang and Gundersen 1977). Bienfang and Szyper (1982) found no indication of a photosynthetic maxima at either the Keahole or Kahe Point sampling sites; however, they did find that the depth of the CML off Keahole Point was 85 ± 9 m which corresponded roughly to the bottom of the transition zone. Because ambient nutrient concentrations were consistently low where these chlorophyll maxima occurred, they concluded that this was an indication of active metabolism by the phytoplankton.

Finally, Bienfang and Szyper (1982) reported that the mixture of surface and deep water discharged by OTEC facilities will spread from the site at depths having similar densities and that these depths will be in the transition zone. Little immediate biostimulation will result in areas where the discharge mixes with oceanic waters and becomes diluted.

III. ZOOPLANKTON

Animals comprising the zooplankton include many of the passively floating or weakly swimming heterotrophic organisms in the water column such as protozoa, especially tintinnids, radiolarians, and foraminifera; large numbers of small crustaceans, like copepods, ostracods, euphausiids, and amphipods; jellyfishes, siphonophores, and worms; molluscs, such as pteropods and heteropods; and eggs and larvae of numerous benthic and nektonic animals (Sverdrup et al. 1946). For convenience, zooplankton can be further divided into microzooplankton, macrozooplankton, and ichthyoplankton. Microzooplankton, which includes organisms such as naupliar and copepodid stages of copepods, ciliate and sarcodine protozoans, and larvaceans, pass through the 202- μ m mesh fraction of filtration netting. Macrozooplankton, which is dominated by copepods and chaetognaths but superimposed in surface waters by eggs and larvae of many nearshore invertebrates and fish, are retained in a 202- μ m mesh net (Sullivan et al. 1981). The following section will discuss only the microzooplankton and macrozooplankton. The ichthyoplankton will be addressed in a later section of this report.

A. Open-Ocean Sites

Results of zooplankton studies conducted during HOTEK-1 through HOTEK-6 (Noda et al. 1980), HOTEK-11 and HOTEK-12 (Noda et al. 1981a), a plume survey (Noda et al. 1981c), and the DOMES survey (Hirota 1977) have been reviewed and are discussed in the section that follows.

1. Biomass and composition--mixed layer

During HOTEK cruises 1 through 4, because of a limited sampling program, Noda et al. (1980) made only general observations on the zooplankton population off Keahole. Briefly, they found that calanoid copepods, by far the most abundant taxonomic group numerically, included

many species that appeared to make extensive diel vertical migrations. Noda et al. also noted significant seasonal changes in the biomass which were not correlated with any of the parameters examined.

On HOTEK-11 and HOTEK-12, there were no significant differences in the dry weight of zooplankton for each depth between cruises or among stations (Noda et al. 1981a). Like the O'OTEC biomass data, dry weight decreased from the surface to the deep strata and was higher at night.

There were also no significant differences at any depth between HOTEK and O'OTEC dry weight biomass data. HOTEK-11 and HOTEK-12 data were also compared with those from HOTEK-1 through HOTEK-6. Measurements of biomass were not significantly different.

During the plume survey, Noda et al. (1981c) collected four samples each from within and out of the plume (control). Copepods collected in a 500- μ m mesh net and stained with Neutral Red were considered alive if the stain was visible in any part of their bodies.

Using a minimum sample size of 200 copepods, and all specimens in samples of Euchaeta marina, Neocalanus robustior, and Corycaeus sp., Noda et al. found that mortalities in the control ranged from 1.1 to 7.5% whereas those in the plume samples ranged between 0.5 and 21.6%. Statistical tests indicated that there was a significantly higher mortality in the plume but no differences among the species.

Estimates of the mortalities in each plume sample due solely to OTEC-1 operation were obtained by subtracting the mean mortality in the control samples from that in the plume. Multiplying the net mortality percentages by the dilution of the plume assessed from fluorometer traces, Noda et al. (1981c) estimated that the mean mortality rate of animals in the warm-water intake of the plant was 100% of entrained animals.

In the analysis of zooplankton abundance and biomass, Noda et al. (1981c) again used four samples each from within and outside the plume. The results showed that the in-plume samples had significantly lower biomass, both in dry weight and ash-free dry weight, but significantly higher percentage of ash than the controls (Table 11).

Noda et al. could not determine whether the differences in biomass were caused by the plume discharge, by the presence of the OTEC-1 platform itself, or by patchiness. They suggested that the differences in percentage of ash may have been the result of either the discharge operation or the presence of the platform. Quantitatively, the plume samples differed from the control in that the former contained a great deal of detritus and microorganisms bound in a matrix of mucous, the source of which was unknown, as well as numerous hydroids and bryozoans which originated from the hull of the vessel.

Zooplankton counts from in-plume and out-plume samples showed little variation except among the most common copepods, the calanoids, which were significantly more abundant outside the plume than within it.

Noda et al. noted that biomass in the 0-200 m stratum during HOTEK-11 and HOTEK-12 was 4.90 mg/m^3 whereas that for HOTEK cruises 1-6 was of 3.32 mg/m^3 . Although the mean for HOTEK-11 and HOTEK-12 was higher, the difference was not significant. They speculated that the slightly higher value for HOTEK-11 and HOTEK-12 may have been the result of differences in handling of the samples. Calanoid copepods predominated in the samples and macroplankton counts showed no clear trend. Thus, no effect from operation of OTEK-1 could be detected in the zooplankton population.

2. Changes with depth

At Keahole, dry weight of zooplankton decreased from the surface to the deep strata and were higher by night than by day in shallow tows (Noda et al. 1981a). The trends in catches by depth are shown in Figure 14.

Analysis of vertical distribution of macrozooplankton in the water column from the DOMES survey showed the highest concentration in the upper 150 m, both day and night, and moderately high concentration between 200 and 900 m (Hirota 1977). Concentrations were usually low near 200 m at Site C and at all sites below 800-900 m.

Table 12 shows the data on standing stocks of macrozooplankton integrated over the upper 1,000 m. Standing stocks in the upper 200 m varied from about 50 to 90% of that for the upper 1,000 m (Hirota 1977).

Concerning the microzooplankton in the DOMES area, Hirota (1977) found the following major features of vertical distribution:

- o Total nauplii, tintinnids, and Microsetella tend to be most numerous at depths less than 40-60 m.
- o Oncaea abundance reached a maximum at depths usually greater than 100 m.
- o Radiolaria and Foraminifera showed relatively small depth variation compared with nauplii, tintinnids, Microsetella, and Oncaea, and were common at all depths sampled.
- o There were at least twofold diel variation in abundance above 75 m for nauplii, tintinnids, and Microsetella, and deeper than 75 m for Oncaea.
- o Microsetella was either absent or low in abundance most consistently at depths below 100 m.
- o The vertical distributions of the five major microplankton taxa were not correlated with hydrographic or algal abundance; however, nauplii, tintinnids, and Microsetella were most likely to be associated with the chlorophyll maximum and discontinuity layers.

Hirota compared numerical abundances of each of the five microplankton taxa with those obtained from around Hawaii (Gundersen et al. 1976) and in the EASTROPAC area (Beers and Stewart 1971) and concluded that the DOMES

area concentrations were lower than those in EASTROPAC by about twofold or more but overlapped in range of values reported from off Hawaii.

3. Seasonal variation

The results of the Keahole sampling showed that zooplankton in the offshore environment exhibited significant seasonal changes in biomass levels (Noda et al. 1980).

Hirota (1977), in reporting on the neuston, macroplankton, and microplankton abundances from the DOMES area, found differences between years (seasons) at all the sites sampled.

Studies on Hawaiian zooplankton collected in 1955-56, showed monthly variations in zooplankton volumes and peak volumes in winter, around January, a spring peak in April, and a fall peak in September (Nakamura 1967). These results contrast with those of King and Hida (1957) who found increased volumes in March-July and lower but variable volumes thereafter. Nakamura concluded that although seasonal volumes appeared to be different, their significance was clouded by some evidence of year-to-year variations. Primary productivity and zooplankton biomass in an oligotrophic gyre are not seasonal but rather related to changes over some different, perhaps longer time scale (McGowan and Hayward 1978).

4. Vertical migration

Diel vertical migrations of some species of zooplankton and micronekton have been studied extensively and are well known in warm tropical waters (Blackburn 1981). In areas of deep light penetration, these animals would be expected to have a relatively large vertical range. For example, in the Pacific, the medium daytime depth of the sound scattering layer is 335 m. Vinogradov (1968) reported that in the subpolar region, the macroplankton occupies much of the water column but diurnal migrations are weak. In the tropics, however, the macroplankton concentrates in narrow layers and undergo extensive diurnal vertical migration. One consequence of vertical movement would be the transfer of organic material to animals living at progressively greater depths. Longhurst (1976) has stated that no evidence exists of migration below 1,700 m.

Data from the HCTEC 1-6 cruises indicated that many species of zooplankton off Keahole appeared to make extensive diel vertical migrations. Nakamura (1967) concluded from his studies of zooplankton volumes in waters around Oahu, Hawaii, that polychaetes, ostracods, calanoid copepods, euphausiids, amphipods, pteropods, and fish larvae all exhibited pronounced diel variations in abundance. Among the calanoid Copepoda, genera such as Pleuromamma, Neocalanus, Candacia, Undinula, and Euchaeta exhibited the most marked diel variation in abundance. Haloptilus was absent from the upper layer of water.

E. Differences at Island Sites

1. Biomass and composition--mixed layer

There was an approximate tenfold difference between biomass collected in shallow plankton tows and those from the 600-1,000 m depth range off Kahe (Noda et al. 1981b). In the shallow tows, night-time biomass was twice as great as that found during the day. Noda et al. also found considerable variability in zooplankton biomass among the cruises; however, they concluded that this variability was not related to seasonal changes.

Tables 13 to 18 show the zooplankton biomass data summarized for the six O'OTEC cruises. The ash-free zooplankton biomass ranged from a low of 0.14 mg/m³ to a high of 25.00 mg/m³, both from cruise 4 in January 1981. Variability in zooplankton biomass was attributed to several sources: subsampling error, variability between replicate tows; differences between stations and between day and night tows; and differences among cruises and among depths.

2. Changes with depth

Off Kahe between the surface and 25 m, there was some evidence of zooplankton patchiness in the portion of the population that made diel migrations. Similar evidence of day and night differences and patchiness was found in the remaining depth ranges above 1,000 m. Also, repeated cruises offered better discrimination of changes than replicate stations or samples (Noda et al. 1981b).

Noda et al. reported that it was not clear which taxa of the zooplankton community will be most affected by OTEC deployment; it was necessary, therefore, to undertake a broadbased investigation of all the taxa found and their abundance. Furthermore, because of the large number of species involved, they concluded that there is a need for a trade off between the number of samples to be processed in a given time and the number of taxa to be identified to genus and species.

For the O'OTEC investigation, Noda et al. identified all animals to class except that the more abundant copepods were identified to genus when possible and occasionally to species. In general, most taxa occurred infrequently in all samples. Most were found more frequently in shallow than deep water and many of the taxa common in shallow water were absent or rare in deep water.

In all samples, copepods made up 73-85% of the total and among the copepods, from 59 to 66% were calanoids except in the reuston samples where calanoids accounted for 38% in day samples and 78% in night collections. Noda et al. suggested that this exception was the result of apparent reverse diel migration of cyclopoids of the Family Corycaidae in and out of the surface layer.

In summary, Noda et al. found that the most abundant group overall was the calanoid copepods and among these, the small herbivorous calanoids of the Families Paracalanidae and Pseudocalanidae were the predominant groups

in the shallow strata. In the deep strata, the calanoids included large, mainly carnivorous animals.

Among the cyclopoids which were only second to calanoids in abundance, three groups predominated--Corycaeidae, which were most abundant in surface samples and Oithona and Oncaea which were dominant in the deep samples. All three were abundant in the 0-25 m samples.

The patterns of absolute abundance that emerged from the study were as follows:

- o Medusae, gastropod larvae, fish eggs, Foraminifera, and Corycaeidae were most abundant at the surface, decreased in abundance with depth, and was more abundant at night in all layers than during the day.
- o The abundance of radiolaria, pelecypod larvae, amphipods, chaetognaths, larvacea, salps, and copepods, such as Arocalanus spp., Paracalanus spp., Clausocalanus spp., Euchaeta spp., Haloptilus spp., Candacia spp., Arcatia negligens, and Oithona spp., was at a maximum below the surface. The abundance of neuston and shallow water forms was greater at night.
- o Ostracods, euphausiids, and copepods such as Oncaea spp., Pleuromamma sp., and Lucicutia spp. were most abundant well below the surface by day. At night these species were much more abundant than they were above 25 m during the day.

3. Seasonal variation

Off Kahe, the temporal variability of zooplankton abundance may not be seasonal (Noda et al. 1981b). Primary productivity and zooplankton biomass in an oligotrophic gyre are not seasonal but rather change over some different, perhaps longer time scale (McGowan and Hayward 1978). Noda et al. suggested that this lack of seasonality is sufficient reason for long pre- and post-deployment sampling periods to detect long-term variability.

4. Vertical migrations

Off Kahe, organisms such as ostracods, euphausiids, and copepods like Oncaea spp., Pleuromamma sp., and Lucicutia spp. migrated vertically, and were found between 25 and 200 m during the day (Noda et al. 1981b). Medusae, gastropod larvae, fish eggs, Foraminifera, and Corycaeidae were non-migrating epipelagic animals, and radiolaria, pelecypod larvae, amphipods, chaetognaths, larvacea, salps, and numerous copepods such as Acrocalanus spp., Paracalanus spp., Clausocalanus spp., Euchaeta spp., Haloptilus spp., Candacia spp., Arcatia negligens, and Oithona spp. appeared to have a vertical migration pattern. However, their increased night-time abundance may be indicative of net avoidance in day-time sampling. Their abundance in deep, daytime samples was not notably greater than their night-time abundance which suggests that no upward migration was occurring; however, because of the wide depth ranges used for the study, more detailed observations are needed.

IV. FISHES

Fishes and other nekton are expected to be attracted to an offshore OTEC structure, thus increasing their concentrations. Nektonic organisms can maintain their location and direction by swimming; however, the intake velocities of an OTEC facility may exceed swimming capabilities, particularly among small species or juveniles. As a first step toward determining OTEC entrainment and impingement impacts on nekton, the species composition and population size of fishes need to be estimated in the vicinity and downstream of the OTEC site ([Hawaii.] DPED 1980).

In waters 6-25 nmi off Kahe Point, micronekton organisms in a 1,200-m water column showed a mean standing stock of 900 organisms and a wet weight of 0.5 kg/100 m² of ocean surface (Maynard et al. 1975). Over half of the number of individuals and their biomasses were composed mostly of small fishes. At night, there were substantial increases in abundance of nekton in shallow water as a result of vertical migration. For micronekton determined to be inhabitants of water deeper than 400 m during the day, Maynard et al. found that about 45% migrated upward at night. During daylight hours, about 90% of the mean total micronekton standing stock were in waters deeper than 400 m ([Hawaii.] DPED 1980).

A. Species of Commercial and Recreational Importance

The commercial fisheries in Hawaiian waters have been described by Manar (1969) and Uchida (1978). The shelf zone, on which most of the world's most productive fisheries are conducted, is narrow and poorly developed in Hawaii. Furthermore, only about 60 of the more than 682 species of fishes, mostly found on the reefs and inshore area, are commercially exploited. The major Hawaiian commercial fisheries are in the open ocean beyond 200 m in depth, where pole-and-line sampans catch skipjack tuna, Katsuwonus pelamis, and longline, handline (ika-shibi), and charter boats harvest deep- and surface-swimming yellowfin tuna, Thunnus albacares, bigeye tuna, T. obesus, albacore, T. alalunga, striped marlin, Tetrapturus audax, blue marlin, Makaira nigricans, black marlin, M. indica, swordfish, Xiphias gladius, shortbill spearfish, Tetrapturus angustirostris, sailfish, Istiphorus platypterus, wahoo, Acanthocybium solandri, and mahimahi, Coryphaena hippurus.

The nearshore fisheries, consisting of a variety of commercial handline, net, trap, and recreational boats, are mainly on a wide array of demersal and benthopelagic species which include pink snapper, Pristipomoides filamentosus, and P. sieboldii, gray snapper, Aprion virescens, red snappers, Etelis carbunculus, and E. coruscans, jacks, Carangidae, goatfish, Mulloidichthys spp. and Parupeneus spp., and sea bass, Epinephelus quernus. Bigeye scad, Selar crumenophthalmus, and mackerel scad, Decapterus macarellus are also major species in this group and their combined landings are second only to total landings of tuna and billfish.

There are a number of commercially valuable fish species in the Kahe area. The abundance of larval and juvenile tunas were studied by Higgins (1970) at a site about 7 km seaward of Kahe and very close to the proposed

offshore OTEC site. Midwater trawl catches of juvenile tunas were much lower in this area than at another site 56 km offshore. Also, almost all bigeye and yellowfin tunas were in the upper layers and small juvenile skipjack tuna were most abundant in the shallow water whereas large ones tended to be more abundant in deep water.

Data from Higgins (1970) and Miller (1979) suggest that an OTEC plant 3 nmi offshore from Kahe Point may be ideally situated with respect to avoiding tuna larvae inshore and tuna juveniles offshore ([Hawaii.] DPED 1980).

A list of fishes of commercial and recreational value inhabiting the offshore waters of Keahole Point has been compiled by Jones and Ryan (1981). Table 19, which has been compiled from catch reports of the Hawaii Division of Aquatic Resources (HDAR), lists the species caught off Keahole and Kahe Points in 1976-80.

In Hawaii, catches are reported according to numbered fishery statistical areas (Figure 15). The inshore area extends just beyond the reefs, roughly 2 nmi from the coastline. The offshore area extends from the outer boundaries of the inshore area to 20 nmi from the coastline.

Jones and Ryan (1981) also listed the following species of fishes that were attracted to the platform and pipe during the operation of Mini-OTEC:

Spotted triggerfish	<u>Canthidermis maculatus</u>
Opelu	<u>Decapterus pinnulatus</u>
Rainbow runner	<u>Elagatus bipinnulata</u>
Mahimahi	<u>Coryphaena hippurus</u>
Pilotfish	<u>Naucrates ductor</u>
Whitetip shark	<u>Pterolamiops longimanus</u>
Kahala	<u>Seriola dumerili</u>
Bigeye scad	<u>Selar crumenophthalmus</u>
Filefish	<u>Alutera scripta</u>
Rudderfish	<u>Kyphosus cinerescens</u>
Yellow tang	<u>Zebrasoma flavescens</u>
Blenny	<u>Istiblennius</u> spp.
Damselfish	<u>Chromis hanui</u>
Whale shark	<u>Rhincodon typus</u>
Skipjack tuna	<u>Katsuwonus pelamis</u>
Yellowfin tuna	<u>Thunnus albacares</u>
Wahoo	<u>Acanthocybium solandri</u>

In a report describing the effects of impingement of marine organisms at Kahe Point as a result of the operation of the existing fossil-fueled electric generating plant, Coles et al. (1982) observed that several commercially important invertebrates and vertebrates were affected. Among the invertebrates were Abralia trigonura, Antarctic slipper lobster, Paribaccus antarcticus, shrimp, Penaeus marginatus, octopus, Octopus cyanea, kona crab, Ranina ranina, and scaly slipper lobster, Scyllarides squammosus. None, however, were caught in sufficient numbers to merit concern. The stomatopod, Squilla oratoria, suffered the highest loss, but this species is not considered of great commercial value.

Among several commercially important species, only the kala, Naso unicornis, was affected in sufficient numbers to warrant attention. Based on extrapolation over 1 year, Coles et al. estimated that about 1,600 kala would be affected, mostly juveniles, and the projected loss would amount to 9.6 kg/yr. The amount, according to them, is well below the 7,700 kg caught in 1978 in the State of Hawaii.

B. Yield and Value

The yield and value of commercial fishing off Keahole and Kahe Points are summarized in Table 19. The data for Keahole Points are from statistical areas 121 and 122 of the Hawaii Fisheries Chart No. 2 (Figure 13). It was necessary to compile the data from these two areas because Keahole Point falls near the division of areas 121 and 122. Data for Kahe Point are from area 422.

Catch, by species, was summarized for 1976-80 and a mean annual catch determined. The values given in HDAR's catch reports are only for weight sold; therefore, the value may be underestimated if the entire catch was not sold. To derive the estimated value of the entire catch, the average price per unit weight sold was calculated from the weight sold and value information and multiplied by the actual weight caught.

The fishing grounds off Keahole and Kahe Points are high-producing regions in the Hawaiian fisheries not only for inshore reef and bottom fishes but also for pelagic species such as skipjack, yellowfin, and bigeye tunas, blue marlin, striped marlin, mahimahi, and wahoo (Table 19). Kailua-Kona, which is located along the leeward coast of the Island of Hawaii roughly 7 nmi south of Keahole Point, is recognized as one of the centers for big-game fishing in the world, and contests such as the International Billfish Tournament are held there annually. The waters off Kailua-Kona are also important for the night handline fishery (ika-shibi) for yellowfin and bigeye tunas. Kahe Point, which is located along the Waianae coast of the Island of Oahu, is a high-producing region for skipjack tuna (Uchida 1970).

Among bottom, benthopelagic, and reef fishes, important catches made off Keahole Point include amberjack, Seriola dumerili; snappers, Pristipomoides filamentosus, Aprion virescens, Etelis carbunculus, E. coruscans, Lutjanus kasmira, and Apareus rutilans; jacks, Carangidae; goatfish, Mulloidichthys auriflamma; bigeye scad, Selar crumenophthalmus, mackerel scad, Decapterus macarellus; red bigeye, Priacanthidae; and squirrelfish, Myripristis spp. Off Kahe, the more important species include jacks, bigeye scad and mackerel scad, surgeonfishes, Naso unicornis and Acanthurus dussumieri, goatfish, Mulloidichthys samoensis and M. auriflamma, and bonefish, Albula vulpes. (Seaweeds, Rhodophyta and Chlorophyta, are also harvested in this area.)

C. Food Chain Effects and Other Considerations

Observations made off Campbell Industrial Park near Kahe Point revealed some interesting facts about the bottom types and inhabitants. Based on dives from 24 to 192 m in the submersible Asherah, Strasburg et

al. (1968) reported that the inshore area between 24 and 107 m was a sloping sandy plain interrupted by rocky ledges 3 to 18 m high. The sandy stretches were featureless and devoid of visible fauna, but in those isolated spots where coral growth or an accumulation of rocky rubble were seen, there were invariably some aggregations of fish, usually butterflyfish, Chaetodontidae, damselfish, Pomacentridae, triggerfish, Balistidae, and surgeonfish, Acanthuridae. Over the sandy bottom, they observed goatfish, Mullidae, flounders, Bothidae, bonefish, and wrasses, Labridae, whereas in midwater they saw large schools of mackerel scad, bigeye scad, jacks, and unicornfish, Naso hexacanthus. Usually, the fishes were concentrated above and in front of ledges.

Strasburg et al. also observed invertebrates in the nearshore depths. Among them were starfishes, Culcita and Linckia; Chondroecidaris, sea urchins, hydrozoans or anthozoans resembling Pennaria but including larger and heavier individuals; and extremely large spiny lobsters, Panulirus spp. that were possibly up to 60 cm long in total length and estimated to weigh 3.2 kg. One unusual aspect of the observation of spiny lobster was that they were on the open bottom unlike reef inhabiting lobsters which are found in deep, dark caves, or beneath protruding ledges. Also observed on the sandy plains were sponges, protruding tubes of annelid worms, and small brittlestars. Between 60 and 107 m, as much as two-thirds of the sea floor was covered by dense beds of a pen shell, Atrina. A bed of spatangid heart urchins consisting of thousands of individuals spaced roughly 30 cm apart were visible at 107 m. The stony coral, Porites, was observed as deep as 107 m, although their occurrence were rather uncommon.

Between 107 and 116 m, the sloping plain gave way to a steep cliff, plunging at an angle of 60°-80° from the horizontal. The cliff of smooth limestone, devoid of any macroscopic demersal fauna, had a textured quality at various places and these held silty deposits as well as gobies, longer-legged shrimp, and lobsterlike crustaceans. Ledges, caverns, and other irregularities on the cliff face sheltered crowds of squirrelfish, moray eels, butterflyfish, and other fishes. Coils of an antipatharian coelenterate, probably Cirripathes, were also common on the cliff as well as various starfish, sponges, and sea urchins down to 192 m. Beds of red coral, Stylaster and Corallium, were seen between 137 and 183 m. In addition, the cliff was "patrolled" by snappers, amberjack, wahoo, and various species of jacks, either singly or in two's and three's.

V. ICHTHYOPLANKTON

A report which summarized ichthyoplankton population studies conducted in the vicinity of Kahe Point during the mid and late 1970's indicated that some data were nearly site specific for the OTEC site ([Hawaii.] DPED 1980). Leis (1978), who reported on 15 species of larval fish collected about 1.9 nmi from the shoreline, found median concentrations of 0-112 larvae/1,000 m³ per species with upper ranges of 7-182 larvae/1,000 m³ per species. He added that 100 fish larvae/1,000 m³ would be a reasonable estimate of the mean fish larvae population at the OTEC site.

The [Hawaii.] DPED (1980) report also provided an estimate of the potential impact of an OTEC plant on the larval fish population. Assuming

that an OTEC plant would entrain about 13.8 million m^3 of surface water per day, DPED estimated that about 1.38 million fish would be impacted per day, based on the population estimate provided by Leis (1978). There is, however, a need to expand the data base on such studies so that a critical evaluation could be made on potential impact. This is particularly true of the potential impact on larval tuna populations because of the importance of adult tunas in the Hawaiian fishery. The larval tuna population in waters 0.6 nmi seaward of Kahe Point can be as high as 441/1,000 m^3 or roughly 10-100 times greater than populations found in oceanic waters of the central Pacific (Miller 1979). Miller postulated that there is a relatively deep source of these larvae, which may migrate inshore in response to upwelling of deep cold water and a shoaling of the thermocline shoreward. The [Hawaii.] DPED report concluded that tuna and other larval fish populations, therefore, may be impacted by OTEC-related alterations of the temperature structure of receiving water in the area as well as by primary entrainment.

A. Spawning Seasons and Locations

The determination of spawning season in fishes is usually based on observations on the condition of gonads, particularly ovaries. Spawning locality, however, is not readily determined unless one observes directly, the emission of ova and milt from mating pairs or observes ova attached to bottom plants, reef, or other substrate.

Other methods are also frequently used to determine spawning season and locality. The presence of larvae is good evidence that spawning occurred recently. And because larval stages of fishes are usually feeble swimmers, one can reasonably assume that the larvae have not strayed or been swept by currents very far from the actual spawning site. Some exceptions are phyllosoma stages of spiny lobsters or leptocephalus stages of anguillids that have a relatively long larval stage and which are carried for great distances by the ocean currents.

The nearshore waters of Kahe Point serve as spawning grounds for a variety of species (Miller et al. 1979). Analysis of the seasonal larval distribution indicated that they were more numerous during summer than winter.

There is also some indication that the deep waters off Kahe Point are important nursery grounds for some species of fish. Juvenile squirrelfish, Holocentrus lacteoguttatus, have been seen in large concentrations at depths between 101 and 183 m (Strasburg et al. 1968).

B. Egg and Larval Abundance and Surface Distribution

Miller et al. (1979) present data on common nearshore marine fish larvae found at Kahe Point. Their data indicate that the inshore and offshore abundance of larvae in winter at Kahe Point was below the mean level (109) for all Oahu sampling sites. In summer, the number of larvae inshore exceeded the summer mean (135) by a considerable margin; however, the offshore total was slightly below the mean.

An ichthyoplankton survey of the nearshore waters of Kauai, Oahu, and Maui in 1972-73 disclosed abundances of tuna larvae as high as 441/1,000 m³ (Miller 1979), an estimate 10-100 times higher than those typical of the central Pacific. Detailed sampling at Kahe Point showed a mean of 7.7 tuna larvae for day samples whereas the night mean was much higher (23.6). Miller also found that day and night subsurface samples yielded higher abundance of tuna larvae than surface samples by a factor of 4.3 and 9.7 times, respectively. The abundance of larvae increased with decreasing distances from shore. Catches off the leeward coast were also higher than those off the windward coast.

The longshore current near Kahe Point flows at a rate of 25-50 cm/sec (Laevastu et al. 1964). Because the current appears to be too strong for feebly swimming tuna larvae of 4 mm to oppose, Miller hypothesized that the high nearshore surface densities of tuna larvae probably originated from a deep source. Two observations he made support this hypothesis. One is that large catches of tuna larvae were made at his leeward station where strong trade winds (4-5 m/sec) tend to push surface waters away from shore. The result is an upset in the hydrostatic equilibrium which could be restored by upwelling. The second observation is that the thermocline, which usually is at 100 m off Hawaii and which serves as a barrier to vertical migration of larvae and vertical transport of water, was observed to ascend the leeward slope off Kahe Point (Figure 16). Thus, it appears likely that large numbers of tuna larvae will be upwelled at Kahe Point by wind-driven currents from horizontal strata containing even higher densities of larvae.

Miller (1974) reported on the results of studies on spatial distribution of fish larvae in relation to variation in their abiotic environment off Kauai, Oahu, and Maui. Chief among the mesopelagic families found were Myctophidae and Gonostomatidae. Also found were offshore pelagic families such as Scombridae, Molidae, and Gempylidae. The 20 most common families encountered in order of their percent overall abundance were Myctophidae (16.3%), Blenniidae (13.9%), Gonostomatidae (11.8%), Gobiidae (11.3%), Pomacentridae (8.9%), Tripterygiidae (6.7%), Molidae (6.4%), Mullidae (3.5%), Apogonidae (3.3%), Carangidae (3.2%), Scombridae (3.0%), Schindleriidae (2.3%), Exocoetidae (2.2%), Tetraodontidae (1.4%), Gempylidae (0.5%), Coryphaenidae (0.5%), Dussumieriidae (0.4%), Scorpaenidae (0.3%), Chlorophthalmidae (0.3%), and Sphyraenidae (0.3%). Miller noted that 92% of all larvae collected belonged to these 20 families and 54 other families were represented in the samples.

C. Vertical Distribution

In a study conducted in the DCMES area, Hirota (1977) found that in the neuston tows and shallow bongo net tows, species of interest to commercial and sport fisheries included larvae of Scombridae, Coryphaenidae, and Istiophoridae. Among midwater forms collected were Myctophidae, Gonostomatidae, Gempylidae, Hemiramphidae, Exocoetidae, Nomeidae, Carangidae, Scomberosocidae, and Labridae.

From deeper bongo net tows made below 200 m, Hirota found very few species compared with the neuston and shallow bongo net tow data. Those species present in the below 200-m tows also occurred in low concentrations.

Hirota concluded that (1) the neuston layer contains some species in very high abundance but which are rather uncommon in the 1-200 m layer, (2) the larvae of commercially important tunas occur more abundantly in the neuston layer than in the 1-200 m layer, (3) the species in the 1-200 m layer are primarily midwater forms, and (4) very few larval fish occur between 200 and 1,000 m.

D. Vertical Migration

Ichthyoplankton constitute a considerable proportion of the midwater plankton in tropical regions (Vinogradov 1968). In the 500-1,000 m layer, they constitute as much as 20-25% of the total mass of net plankton. In the middle latitudes, however, the picture changes considerably and the fish biomass in the deep layers is higher than in the tropical regions but its proportion in the plankton is considerably lower.

VI. OTHER IMPORTANT BIOLOGICAL RESOURCES

A. Endangered Species

Cumulative effects of commercial OTEC development may significantly impact threatened and endangered species. For example, migratory threatened and endangered species could emigrate from an area that becomes impacted from OTEC operation, thus possibly disrupting the animal's reproductive or feeding activities. Habitats could also be affected.

Payne (1979) reported that 22 marine mammal species may occur in Hawaiian waters including 2 mysticetes, 19 odontocetes, and one pinniped (Table 20). The humpback whale, Megaptera novaengliae, one of the most abundant cetaceans in Hawaii, is an endangered species which migrates into Hawaiian waters in winter to breed. A second endangered species, the Hawaiian monk seal, Monachus schauinslandi, is present in Hawaii; however, the population resides in the Northwestern Hawaiian Islands and away from potential OTEC sites.

Dolphins of Stenella, the most numerous small odontocetes in Hawaii, have been sighted in coastal areas throughout the island chain. Payne noted a 250-member population of spinner dolphins, S. longirostris, off Keahole Point, a potential OTEC area. The bottlenosed dolphin, Tursiops spp., is also fairly common but the false killer whale, Pseudorca crassidens, and pygmy killer whale, Feresa attenuata, are less common.

The OTEC development in Hawaii is not expected to significantly impact threatened and endangered species.

B. Corals

Estimates are available of changes that have occurred in coral coverage near Kahe Point during the pre- and postconstruction phases of the offshore outfall for the Hawaiian Electric power plant. Beginning in 1973 and through 1977, the study showed that pronounced decline in coral coverage occurred as a result of general disturbances associated with outfall construction including underwater blasting, dredging, sedimentation, and turbidity. Decrease in coral coverage from 1978 to 1979, which approached the high values of earlier years, was highly significant compared with previous years. The rate of decline from 1980 to 1981 was 4.5-5.0 times the rate for the other years (Coles et al. 1982).

The drastic decrease in coral coverage at Kahe Point from 1979 to 1980, however, was not attributable to the operation of the outfall but to effects of a storm in January 1980. The storm waves generated at that time resulted in breakage of corals, scouring of reef surfaces by wave-suspended sand, and burial of living coral. Coles et al. concluded from their study that the detrimental effects of a single natural event were far more devastating than any stressful influences produced before or after the storm.

The results of the Kahe study also demonstrated that there has been no detrimental influence by the Kahe outfall on the coral. Coral decline has been greater with increased distance from the outfall. This pattern occurred rather consistently for all years examined except 1979 to 1980 when a significant correlation existed between changes in coral coverage and the outfall. In 1981, however, changes in total coral coverage were less negative at stations close to the outfall. In fact, Coles et al. concluded that there was an indication of a benign or even positive influence of the Kahe outfall on coral coverage on most of the Kahe reef in 1981.

The effects of thermal effluent on coral were investigated at Guam. At the Tanguisson Plant where the intake temperature varied between 26°C and 29°C and the discharge temperature between 30°C and 34°C, there was significantly less coverage of the substratum by hermatypic corals along the reef margin near the thermal effluent than in areas outside its influence (Neudecker 1976), thus demonstrating that the thermal effluent has a negative effect on the coral community. Furthermore, the number of coral species, coral recruitment, and biomass accumulation were significantly less near the area of thermal effluent than in areas away from it.

VII. SUMMARY

This document presents a review of pertinent biological information characteristic of potential OTEC sites in the Pacific Ocean. Ideal ocean thermal resource can be found year round in the tropics between lat. 20°N and 20°S. Achieving maximum efficiency from an OTEC plant would require information on bottom topography and profile, magnitude of temperature change between surface and deep water, substrate, permanent water flow,

tidal, wind-driven; and inertial currents, mass transport, climatic conditions, benthic properties, and chemical properties of the sea water.

Some of the potential sites in the Pacific that meet temperature-depth requirements for OTEC operation include French Polynesia, New Caledonia, Guam, Hawaiian Islands, Japan, Philippine Islands, west coast of Mexico, and Taiwan. A Pacific plant ship site is also reviewed.

For open-ocean situations, data from OTEC-1 and DCMFS are reviewed. Off Keahole where OTEC-1 experiments were conducted, the chlorophyll a concentration was low at the surface and ranged from 0.03 to 0.18 mg/m³. A subsurface chlorophyll maximum, ranging between 0.17 and 0.62 mg/m³ occurred between 64 and 94 m. Primary production ranged between 8.64 and 224.40 mgC/m²/day. Compensation depth was estimated to be 125 m.

At the DCMFS survey site, surface chlorophyll values averaged 0.117 mg/m³. The CML was located deeper in summer (69 ± 24 m) than in winter (54 ± 30 m) but the difference was not significant. Primary production in the euphotic zone was 120 mgC/m²/day in summer and 144 mgC/m²/day in winter.

The composition of the phytoplankton community was similar at both oceanic sites. By order of importance in numbers, the groups included flagellates, dinoflagellates, diatoms, and coccolithophores; in terms of cell volume, the order of importance at the Keahole site was dinoflagellates, flagellates, diatoms, and coccolithophores.

Seasonal variation in phytoplankton standing crop was also reviewed. At the DCMFS site, winter chlorophyll a concentrations were much higher than summer values.

In reviewing island sites, data collected during the Kahe survey off the Island of Oahu are reviewed. The CML was located rather deep, at 86 m, typical of more oceanic systems. Chlorophyll a concentration was 0.27 µg/liter. The primary productivity values reached 60.4 ± 25.6 gC/m²/yr, typical of subtropical gyre water. Compensation depth 146 m.

The community composition in the Kahe environment was dominated by organisms ≤ 3 µm. Seasonal variation was observed in pigment levels, ATP values, and photosynthetic rates. The biomass, however, showed no significant seasonal changes.

Differences between open-ocean and island sites are also reviewed. Differences in the nature and magnitude of temporal variations are related to the physical environment. Variability in physical processes at Keahole produces a complex biological system, whereas at Kahe, the physical processes are less intense thus creating a more gradual and systematic temporal cycle.

Data from a plume survey conducted off Keahole Point were also reviewed.

Concerning zooplankton, investigators found that for open-ocean situations, the Keahole area was dominated by calanoid copepods, of which many species made extensive diel migrations. The biomass also showed significant seasonal changes. Biomass usually decreased from the surface to the deep strata.

Experiments during the plume survey off Keahole indicated total mortality of entrained zooplankton.

Biomass of zooplankton in the 0-200 m stratum at Keahole averaged 3.32 mg/m³ on six cruises and 4.90 mg/m³ on two later cruises; however, the difference in means was not significant. Zooplankton abundance usually changed with depth at the Keahole and DOMES sites, and concentrations were highest in the upper 150 m both day and night. Seasonally, the zooplankton off Keahole exhibited significant changes. Many species of zooplankton at Keahole made extensive diel migrations.

For the island site, it was found that zooplankton biomass in the Kahe environment varied by tenfold between shallow and deep tows; the shallow tows had the higher values. The biomass at night near the surface was also twice as great as that during the day. There is some evidence of zooplankton patchiness in the portion of the population making diel migrations. Off Kahe, copepods made up 73-85% of the total numbers of zooplankton. Among copepods, calanoids dominated: 38% of the day samples and 78% of the night samples.

Temporal variability of zooplankton abundance was not entirely seasonal off Kahe. Some animals in the zooplankton community (ostracods, euphausiids, and copepods), made vertical migrations; medusae, gastropod larvae, fish eggs, Foraminifera, and Corycaeiidae did not make vertical migrations.

A list of commercially important fishes caught off Keahole and Kahe Points in 1976-80 is presented, together with the mean annual catch and value. By far, the most important species are the pelagic tunas and billfishes. The nearshore fisheries are dominated by bigeye scads and mackerel scads and members of the snapper-grouper complex including jacks or crevalles. Species affected by the operation of an oil-fired electric generating plant at Kahe Point are also reviewed.

The benthic community near Kahe is extremely diverse; the pen shell, Atrina, predominated in some areas and spatangid heart urchins were numerous in other areas.

It was estimated that an OTEC plant would entrain 13.8 million m³ of surface water per day and impact 1.38 million larvae. Additional studies, however, are required to make a critical evaluation of potential impact.

The nearshore waters off Kahe serve as spawning areas for a wide variety of fishes. The offshore waters may also be nursery grounds for some species.

At the DOMES site, the neuston layer contains some species in high abundance but are rather uncommon in the 1-200 m stratum. Larvae of commercially important tunas were abundant in the neuston layer. Species found in the 1-200 m layer were primarily those associated with midwater depths. Larval fish were uncommon between 200 and 1,000 m.

Studies conducted on impact of an existing oil-fired power plant's outfall on corals in the Kahe environment indicates no detrimental effects. Rather, decrease in coral coverage was mainly attributable to effects of storms.

VIII. LITERATURE CITED

Armstrong, R. W. (editor).

1973. Atlas of Hawaii. Univ. Press Hawaii, Honolulu, 222 p.

Avery, W. H.

1980. Ocean thermal energy conversion contribution to the energy needs of the U.S. Johns Hopkins APL Tech. Dig. 1:101-107.

Bathen, K. H.

1975. A further evaluation of the oceanographic conditions found off Keahole Point, Hawaii, and the environmental impact of nearshore ocean thermal energy conversion plants on subtropical Hawaiian waters. Final Report. Submitted to Dep. Plann. and Econ. Develop., State of Hawaii, Honolulu, 77 p.

1978. Circulation atlas for Oahu, Hawaii. University of Hawaii Sea Grant Program, 93 p.

Beers, J. R., and G. L. Stewart.

1971. Microzooplankton in the plankton communities of the upper waters of the eastern tropical Pacific. Deep-Sea Res. 18:861-883.

Bienfang, P. K.

1977. Survey of the biological properties in the water column off Keahole Point, Hawaii. In K. Bathen (editor), The behavior of near surface ocean currents, plankton biology, benthic currents and ocean temperatures to depths of 2,200 feet at a potential OTEC site off Keahole Point. Univ. Hawaii Ocean Eng., Tech. Rep., 92 p.

Bienfang, P., and K. Gundersen.

1977. Light effects on nutrient-limited, oceanic primary production. Mar. Biol. 43:187-199.

Bienfang, P. K., and J. P. Szyper.

1982. Photosynthetic response of subtropical phytoplankton populations to deep water nutrient enrichment. Lawrence Berkeley Lab., Univ. Calif., Earth Sci. Div. LBID-467, 24 p.

Blackburn, M.

1981. Low latitude gyral regions. In A. R. Longhurst (editor), Analysis of marine ecosystems, p. 3-29. Acad. Press, Lond.

- Coles, S. L., D. T. Fukuda, and C. R. Lewis.
1982. Kahe generating station NPDES monitoring program. Annual Report, vol. I--Text. Environ. Dep., Hawaiian Electric Co., Inc., Honolulu, 221 p.
- Cox, D. C., and S. F. Mink.
1963. The tsunami of May 23, 1960, in the Hawaiian Islands. Bull. Seismol. Soc. Am. 63:1191-1209.
- Cushing, D. H.
1981. Temporal variability in production systems. In A. R. Longhurst (editor), Analysis of marine ecosystems, p. 443-471. Acad. Press, Lond.
- Dames & Moore.
1970. Proposed refinery, Barbers Point, Oahu, Hawaii. Final Report to Dillingham Petroleum Corp., Rep. No. 3964-036-11.
- Dunbar, M. J.
1975. Productivity of marine ecosystems. In U.S. National Committee for the International Biological Program, Proceedings, Productivity of World Ecosystems, p. 27-31.
- El-Sayed, S. Z., and S. Taguchi.
1979. Phytoplankton standing crop and primary productivity in the tropical Pacific. In J. L. Bischoff and D. Z. Piper (editors), Marine geology and oceanography of the Pacific manganese nodule province, p. 241-286. Plenum Press, N.Y.
- Eppley, R. W., E. H. Renger, E. L. Venrick, and M. M. Mullin.
1973. A study of plankton dynamics and nutrient cycling in the central gyre of the North Pacific Ocean. Limnol. Oceanogr. 18:534-551.
- Forti, G.
1966. Light energy utilization in photosynthesis. In C. R. Goldman (editor), Primary productivity in aquatic environments. Proceedings of an I.B.P. PF Symposium, Pallanza, Italy, April 26-May 1, 1965, p. 17-35. Berkeley Univ. Calif. Press, Berkeley.
- Fryxell, G. A., S. Taguchi, and S. Z. El-Sayed.
1979. Vertical distribution of diverse phytoplankton communities in the central Pacific. In J. L. Bischoff and D. Z. Piper (editors), Marine geology and oceanography of the Pacific manganese nodule province, p. 203-239. Plenum Press, N.Y.
- Gilmartin, M., and N. Revelante.
1974. The "island mass" effect on the phytoplankton and primary production of the Hawaiian Islands. J. Exp. Mar. Biol. Ecol. 16:181-204.

- Gross, M. G.
1972. Oceanography: A view of the Earth. Prentice-Hall, Inc., Englewood Cliffs, N. J., 581 p.
- Gundersen, K. R., J. S. Corbin, C. L. Hanson, M. L. Hanson, R. B. Hanson, D. J. Russell, A. Stoller, and O. Yamada.
1976. Structure and biological dynamics of the oligotrophic ocean photic zone off the Hawaiian Islands. Pac. Sci. 30:45-68.
- Hasle, G. R.
1959. A quantitative study of phytoplankton from the equatorial Pacific. Deep-Sea Res. 6:38-59.
- Haven, K. F.
1981. Ocean thermal energy conversion systems for Hawaii. In Hawaii integrated energy assessment, vol. II. Alternate energy technologies for Hawaii, p. 51-84. Dep. Plann. and Econ. Develop., State of Hawaii, Honolulu, and Lawrence Berkeley Lab., Univ. Calif. Berkeley, Berkeley.
- [Hawaii.] Department of Planning and Economic Development.
1980. State of Hawaii public sector ocean thermal energy conversion program, 1980-81. Dep. Plann. and Econ. Develop., State of Hawaii, Honolulu, 12 p.
- Higgins, B. E.
1970. Juvenile tunas collected by midwater trawling in Hawaiian waters, July-September 1967. Trans. Am. Fish. Soc. 99:60-69.
- Hirota, J.
1977. DOMES zooplankton. Text. Final Report. Hawaii Inst. Mar. Biol. and Dep. Oceanogr., Univ. Hawaii, Honolulu, 247 p.
- Homma, T., and H. Kamogawa.
1979. An overview of the Japanese OTEC development. Paper presented at the 6th OTEC Conference, June 19-22, 1979, Wash., D.C., p. 2A3/1-2A3/5. Preprints vol. I.
- Homma, T., H. Kamogawa, S. Nagasaki, H. Uehara, T. Teramoto, and T. Kajikawa.
1979. Design considerations on 100MWe commercial scale OTEC power plant and a 1MWe class engineering test plant. Paper presented at the 6th OTEC Conference, June 19-22, 1979, Wash., D.C., p. 4B2/1-4B2/7. Preprints vol. I.
- Honjo, S., and H. Okada.
1974. Community structure of coccolithophores in the photic layer of the mid-Pacific. Micropaleontology 20:209-230.

Johnson, P. W., and A. J. Horne.

1979. Phytoplankton and biomass distribution at potential OTEC sites. Paper presented at the 6th OTEC Conference, June 19-22, 1979, Wash. D.C., p. 7D4/1-7D4/5. Preprints vol. II.

Jones, A. T., and C. J. Ryan.

1981. List of fish at a proposed OTEC site off Ke-ahole Point, Hawaii, derived from commercial fish records, 1959-1978. Lawrence Berkeley Lab., Univ. Calif. Berkeley, Earth Sci. Div., IBL-12666, 13 p.

King, J. E., and T. S. Hida.

1957. Zooplankton abundance in the central Pacific, Part II. U.S. Fish Wildl. Serv., Fish. Bull. 57:365-395.

Laevastu, T., D. E. Avery, and D. C. Cox.

1964. Coastal currents and sewage disposal in the Hawaiian Islands. Final Report. Hawaii Inst. Geophys., Univ. Hawaii, Honolulu, 101 p.

Lassuy, D. R.

1979. Oceanographic conditions in the vicinity of Cabras Island and Glass Breakwater for the potential development of ocean thermal energy conversion on Guam. Univ. Guam Mar. Lab., Tech. Rep. 53, 30 p.

Leis, J. M.

1978. Distributional ecology of ichthyoplankton and invertebrate macrozooplankton in the vicinity of a Hawaiian coastal power plant. Ph. D. Dissertation, Univ. Hawaii, Honolulu, 317 p.

Liang, N. K., J. Wang, and W. C. Lin.

1980. The OTEC resources assessment in Taiwan (I). Acta Oceanogr. Taiwanica, Sci. Rep. Natl. Taiwan Univ. 11:89-104.

Liang, N. K., N. J. Kou, and J. Wang.

1981. The OTEC resources assessment in Taiwan (II). Acta Oceanogr. Taiwanica, Sci. Rep. Natl. Taiwan Univ. 12:84-93.

Longhurst, A. R.

1976. Vertical migration. In D. H. Cushing and J. J. Walsh (editors), The ecology of the seas, p. 116-137. W. B. Saunders Co., Toronto.

Manar, T. A.

1969. Hawaiian fisheries. In F. E. Firth (editor), Encyclopedia of marine resources, p. 295-298. Van Nostrand Reinhold Co., N.Y.

Marchand, P.

1979. French OTEC program. Paper presented at the 6th OTEC Conference, June 19-22, 1979, Wash., D.C., p. 2A2-1/2A2/7. Preprints vol. I.

Marchand, P.

1980. Recent French OTEC work in the area of CTEC systems. Paper presented at the 7th OTEC Conference, June 2-5, 1980, Wash. D.C., p. 9.5-1 to 9.5-12, Preprints vol. II.

Marsh, J. A., Jr., and J. E. Doty.

1976. The influence of power plant operations on the marine environment in Piti Channel, Guam: 1975-76 observations. Univ. Guam Mar. Lab., Tech. Rep. 26, 57 p.

Marshall, H. G.

1970. Phytoplankton in tropical surface waters between the coast of Ecuador and the Gulf of Panama. J. Wash. Acad. Sci. 60:18-21.
1972. Phytoplankton composition in the southeastern Pacific between Ecuador and the Galapagos Islands. Proc. Biol. Soc. Wash. 85:1-38.

Maynard, S. D., F. V. Riggs, and J. F. Walters.

1975. Mesopelagic micronekton in Hawaiian waters: Faunal composition, standing stock, and diel vertical migration. Fish. Bull., U.S. 73:726-736.

McGowan, J. A., and T. L. Hayward.

1978. Mixing and oceanic productivity. Deep-Sea Res. 25:771-793.

Miller, J. M.

1974. Nearshore distribution of Hawaiian marine fish larvae: Effects of water quality, turbidity, and currents. In J. H. S. Blaxter (editor), The early life history of fish, p. 217-231. Springer-Verlag, N.Y.
1979. Nearshore abundance of tuna (Pisces: Scombridae) larvae in the Hawaiian Islands. Bull. Mar. Sci. 29:19-26.

Miller, J. M., W. Watson, and J. M. Leis.

1979. An atlas of common nearshore marine fish larvae of the Hawaiian Islands. Sea Grant Misc. Rep., UNIHI-SEAGRANT-MR-80-02, 179 p.

Moiseev, P. A.

1969. The living resources of the world ocean. Moskva Izdatel'stvo. Transl. from Russian by Israel Program Sci. Transl., 1971, 334 p. Available U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA as TT 50026.

Nakamura, E. L.

1967. Abundance and distribution of zooplankton in Hawaiian waters, 1955-56. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 544, 37 p.

Neudecker, S.

1976. Effects of thermal effluent on the coral reef community at Tanguisson. Univ. Guam Mar. Lab., Tech. Rep. 30, 55 p.

- Newell, G. R., and R. C. Newell.
1963. Marine plankton. Hutchinson Educational Ltd., Lond., 244 p.
(Rev. ed. 1973.)
- Noda, E. K.
1981. Current data from the Kahe Point, Oahu and Keahole Point, Hawaii OTEC benchmark sites, June 1980-June 1981. Univ. Hawaii/J. K. K. Look Lab. Oceanogr. Eng. Tech. Rep. 49, var. pag.
- Noda, E. K., and Associates.
1982. Current measurements off Kahe Point, Oahu in support of the OTEC program. Prepared for the Dep. Plann. and Econ. Develop., State of Hawaii, Honolulu, var. pag.
- Noda, E. K., P. K. Bienfang, and D. A. Ziemann.
1980. OTEC environmental benchmark survey off Keahole Point, Hawaii. Univ. Hawaii/J. K. K. Look Lab. Oceanogr. Eng., var. pag.
(Contract Rep. 80-1.)
- Noda, E. K., P. K. Bienfang, W. J. Kimmerer, and T. W. Walsh.
1981a. Environmental surveys during operation and following removal of the OTEC-1 system off Keahole Point, Hawaii. Univ. Hawaii/J. K. K. Look Lab. Oceanogr. Eng., Tech. Rep. 52, var. pag.

1981b. OTEC environmental benchmark survey, Kahe Point, Oahu. Final Report. Univ. Hawaii/Lawrence Berkeley Lab., Contract Rep. HNEI-81-05, var. pag.

1981c. Plume survey, OTEC-1 mixed-water discharge, April 11-12, 1981. Lawrence Berkeley Lab., Univ. Calif. Berkeley, Earth Sci. Div., LBL-12951, 116 p.
- Ocean Data Systems, Inc.
1977. OTEC thermal resource report for Hawaii. Ocean Data Systems, Inc., Monterey, Calif., 16 p.
- Okada, H., and S. Honjo.
1973. The distribution of oceanic coccolithophorids in the Pacific. Deep-Sea Res. 20:355-374.
- Parsons, T., and M. Takahashi.
1973. Biological oceanographic processes. Pergamon Press, Oxford, 186 p.
- Payne, S. F.
1979. The marine mammal fauna of potential OTEC sites in the Gulf of Mexico and Hawaii. Paper presented at the 6th OTEC Conference, June 19-22, 1979, Wash. D.C., p. 7D5/1-7D5/9. Preprints vol. II.
- Rampi, L.
1952. Ricerche sul microplancton di superficie del Pacifico tropicale. Bull. Inst. Oceanogr. (Monaco) 1.014:1-16.

Riley, G. A.

1970. Particulate organic matter in sea water. In F. S. Russell and M. Yonge (editors), *Advances in marine biology* 8:1-118. Acad. Press, N.Y.

Seckel, G. R.

1955. Mid-Pacific oceanography, Part VII, Hawaiian offshore waters, September 1952-August 1953. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 164, 250 p.

Semina, H. J.

1974. Pacific phytoplankton. [In Russ., Engl. summ.] Publishing House Nauka, Moscow, 239 p.

Sharp, J. H., M. J. Perry, E. H. Renger, and R. W. Eppley.

1980. Phytoplankton rate processes in the oligotrophic waters of the central North Pacific Ocean. *J. Plankton Res.* 2:335-353.

Shuman, F. R., and C. J. Lorenzen.

1975. Quantitative degradation of chlorophyll by a marine herbivore. *Limnol. Oceanogr.* 20:580-586.

Shupe, J. W.

1982. Energy self-sufficiency for Hawaii. *Science* (Wash. D.C.) 216:1193-1199.

Smayda, T. J.

1966. A quantitative analysis of the phytoplankton of the Gulf of Panama. [In Engl. and Span.] *Bull. Inter-Am. Trop. Tuna Comm.* 11:355-612.

Sorokin, Y. J.

1981. Microheterotrophic organisms in marine ecosystems. In A. R. Longhurst (editor), *Analysis of marine ecosystems*, p. 293-342. Acad. Press, Lond.

Sournia, A.

1970. A checklist of planktonic diatoms and dinoflagellates from the Mozambique Channel. *Bull. Mar. Sci.* 20:678, 696.

Strasburg, D. W., E. C. Jones, and R. T. E. Iversen.

1968. Use of a small submarine for biological and oceanographic research. *J. Cons. Cons. Perm. Int. Exp. Mer* 31:410-426.

Sullivan, S. M., M. D. Sands, J. R. Donat, F. Jepsen, M. Smockler, and J. F. Villa.

1981. Draft environmental assessment ocean thermal energy conversion (OTEC) pilot plants. Lawrence Berkeley Lab., Univ. Calif., Earth Sci. Div., IBL-12328, var. pag.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming.

1946. *The oceans*. Prentice-Hall Inc., N.Y., 2d ed., 1,087 p.

Uchida, R. N.

1970. Distribution of fishing effort and catches of skipjack tuna, Katsuwonus pelamis, in Hawaiian waters by quarters of the year, 1948-65. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 615, 37 p.

1978. The fish resources of the western central Pacific islands. FAO Fish. Circ. 712, 53 p.

U.S. Department of Commerce.

1980. Ocean thermal energy conversion environmental issues discussion paper. NOAA, Office of Ocean Minerals and Energy, Wash. D.C., var. pag.

Venrick, E.

1969. The distribution and ecology of oceanic diatoms in the North Pacific. Ph. D. Dissertation. Univ. Calif. San Diego, 684 p. (University microfilms, Ann Arbor.)

Vinogradov, M. E.

1968. Vertical distribution of the oceanic zooplankton. Moscow, Acad. Nauk SSSR, Inst. Okeanol. Transl. from Russian by Israel Program Sci. Transl. 1970, 339 p. Available U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA as TT 69-59015.

Westlake, D. F.

1966. Theoretical aspects of the comparability of productivity data. In C. R. Goldman (editor), Primary productivity in aquatic environments. Proceedings of an I.B.P. PF Symposium, Pallanza, Italy, April 26-May 1, 1965, p. 313-322. Berkeley Univ. Calif. Press, Berkeley.

Wolff, W. A.

1979a. OTEC thermal resource report for Guam. Prepared for U.S. Dep. Energy, HCP/T2898-01/7, var. pag.

1979b. OTEC thermal resource report for Manila, Philippine Islands. Prepared for U.S. Dep. Energy, HCP/T2898-01/8, var. pag.

1979c. OTEC thermal resource report for Pacific plant ship 5-10°N, 90-95°W. Prepared for U.S. Dep. Energy, HCP/T2898-01/3, var. pag.

1979d. OTEC thermal resource report for western coast Mexico. Prepared for U.S. Dep. Energy, HCP/T2829-01/5, var. pag.

Yentsch, C. S.

1966. The relationship between chlorophyll and photosynthetic carbon production with reference to the measurement of decomposition products of chloroplastic pigments. In C. R. Goldman (editor), Primary productivity in aquatic environments. Proceedings of an I.B.P. PF Symposium, Pallanza, Italy, April 26-May 1, 1965, p. 323-346. Berkeley Univ. Calif. Press, Berkeley.

Yuen, P. C.

1981. Ocean thermal energy conversion: A review. Hawaii Natural Energy Institute, Univ. Hawaii at Manoa. HNEI-81-03, 173 p.
(Based on a paper prepared for Florida Solar Energy Center's Solar Technology Assessment, March 1981.)

Text Footnote

¹°C is used to denote degree on a centigrade scale. °C is used to denote an actual reading.

²In an open-cycle system, the warm water is the working fluid. In a partial vacuum, the fluid is flash-evaporated and the resulting steam is driven across the turbine and thence to a heat exchanger where the vapor is condensed by the cold-water flow. The condensate is fresh water and is either discharged with the cold water or used for other purposes. In a closed-cycle system, warm water drawn from the surface provides heat which is transferred through a heat exchanger to a working fluid, for example, ammonia, Freon, propane, or other compounds. Enclosed in a partial vacuum, the working fluid is evaporated by the heat and the resulting high-pressure vapor drives a turbine to produce electricity. Cold water is then pumped from the deep layers to condense the low-pressure vapor in a second heat exchanger. The working fluid is then pumped back and recycled (Haven 1981).

³M. Takahashi, and P. Bienfang. Manuscr. in prep. Size structure of phytoplankton biomass and photosynthesis in subtropical waters.

TABLE 1. Summary of site parameters (from Wolff 1979a).

Site	Range distance (in km) to shore from 1,000 m	Monthly mean mixed layer depth meters	Monthly mean surface currents (cm/sec)	Sea state maximum percent of time >3 m	Number tropical cyclones per year
Sri Lanka	22-55	30-80	25-62	3	0.2-1.2
Mombasa	33-130	30-90	30-62	2	0.0-0.1
Jakarta	18-60	55-80	25-52	2	0.0-0.1
Dampier Land	265-417	30-80	25-47	4	0.4-1.2
Manila	6-82	20-80	30-52	5	4.0-6.0
Guam	7-18	60-120	30-47	5	2.0-3.0
Off Mexico	5-104	10-30	25-31	2	0.6-4.0
Plant ship Pacific	--	0-30	30-52	2	0.0-2.0
Ivory Coast	33-52	0-30	25-31	2	0.0-0.1
Plant ship Caribbean	--	40-110	30-62	3	0.6-1.2

TABLE 2. Summary of site parameters (from Wolff 1979a).

Site	Monthly mean temperature (°C)		Monthly mean temperature (°C) 1,000 m	Annual mean ΔT (°C)		Annual mean ΔT (°C) 1,000 m		Coldest monthly mean ΔT (°C) 500 m		Coldest monthly mean ΔT (°C) 1,000 m	
	surface range			ΔT (°C) 500 m		ΔT (°C) 1,000 m					
Sri Lanka	27.5-28.6		6.5-6.7	18.0		21.3		17.5		20.8	
Mombasa N	25.4-28.7		7.2-7.5	17.0		19.5		15.6		18.2	
Mombasa S	25.5-28.4		6.3-7.0	18.0		20.2		15.9		18.5	
Jakarta	27.2-29.0		5.1-5.6	19.1		22.8		17.9		21.9	
Dampier Land	25.6-28.2		4.9-5.0	19.1		22.6		17.4		20.7	
Manila	27.1-29.5		4.4-4.6	20.0		24.0		18.6		22.6	
Guam	27.7-29.2		4.3-4.4	21.1		24.1		20.4		23.4	
Off Mexico	22.5-28.0		4.4-4.5	17.6		20.9		14.9		18.0	
Plant ship Pacific	27.1-28.5		4.6-4.8	19.4		22.8		18.1		21.7	
Ivory Coast	24.3-28.1		4.5	19.2		22.1		16.8		19.7	
Plant ship Caribbean	26.4-28.4		5.0-5.3	18.1		22.4		17.2		21.3	

TABLE 3. Number of phytoplankton species (mostly at the specific level) found in different studies of the Pacific Ocean (from Fryxell et al. 1979).

Reference	Location	Method	Diatoms	Dinoflagellates	Coccolithophorids	Other
Rampi 1952	Equatorial, 165°-175°W	Surface net tows	40	169	--	6
Hasle 1959	Equatorial, 145°W	Water samples	42	53	33	10
Smayda 1966	Inshore tropical waters, Gulf of Panama	Water samples	175	105	22	24
Venrick 1969	North of Hawaii, oceanic and neritic 155°W, between 26° and 56°N	Net and water samples	110	---	--	--
Marshall 1970	Peru Current, Ecuador to Gulf of Panama	Water samples	39	9	3	2
Marshall 1972	Galapagos Islands to Ecuador	Water samples	57	31	16	7
Semina 1974	Review of entire Pacific, oceanic and coastal	Net and water samples	272	683	48	21
Honjo and Okada 1974	155°W, off Alaska to west of Tahiti	Filtered water samples	--	--	90	--
Present study	DOMES area	Net and water samples	163	122	48	15

TABLE 4. Ten most abundant groups in order of decreasing abundance determined by total number of cells counted in discrete water samples collected during DOMES cruises 1975-76 (from Fryxell et al. 1979).

-
1. Flagellates and monads
 2. Gephyrocapsa huxleyi (Lohm.) Reinhardt
 3. Gymnodiniaceae
 4. Yellow cells
 5. Gephyrocapsa oceanica Kamptner
 6. Nitzschia bica pitata Cleve
 7. Oxytoxum variable Schiller
 8. Nitzschia lineola Cleve
 9. Nitzschia closterium (Ehrenberg) Wm. Smith
 10. Gephyrocapsa ericsonii McIntyre and Bé
-

Table 5.--Phytoplankton species and abundance at potential OTEC sites.
(from Johnson and Horne 1979).

Phytoplankton	Hawaii	Gulf	Puerto Rico
Diatoms	Rank	Rank	Rank
Amphiprora sp.	--	--	Rare
Asterionella sp.	--	--	Rare
Bacteriastrium			
delicatum	Rare	--	--
B. elongatum	Rare	--	--
Bacteriastrium sp.	Rare	--	Rare
Chaetoceros			
coarctatus	Rare	--	--
C. convolutum	Rare	--	--
C. didymus var.			
anglica	--	Rare	--
C. lorenzianus	Rare	Dominant	--
C. messanicase	Common	--	--
Chaetoceros sp.	Common	--	Rare
Climacodium			
frauenfeldianum	Rare	--	--
Coscinodiscus			
excentricus	Common	--	--
C. lineatus	Rare	Common	--
C. marginatus	Rare	--	--
Dactyliosolen			
mediterraneus	Dominant	--	--
Eucampia zoodiacus	Rare	--	--
Grammatophora sp.	--	--	Rare
Guinardia flaccida	--	Rare	--
Hemiaulus hauckii	Common	--	Rare
Hemiaulus sp.	Rare	--	Rare
Leptocylindrus			
danicus	Rare	Common	--
Licomorpha			
abbreviata	--	--	Rare
Licomorpha sp.	--	--	Rare
Mastogloia rostrata	Rare	--	--
Navicula carnifera	--	--	Rare
Navicula sp.	Dominant	--	Common
Nitzschia closterium	Dominant	--	Dominant
N. delicatissima	Rare	--	--
N. longissima	Rare	Rare	Rare
Nitzschia sp.	--	Dominant	Common
Planktoniella sol	Rare	--	--
Pleurosigma sp.	--	--	Rare
Pseudoecunatia			
deliolus	Rare	--	--
Rhizosolenia alata	Rare	--	--
R. bergonii	--	Rare	--
R. cylindrus	Rare	--	--
R. hebetata			
f. hiemalis	Rare	--	--
f. semispina	Rare	--	--
R. imbricata			
var. shrubsolei	Rare	--	Rare
R. styliformis	--	--	Rare
Surirella sp.	--	--	Rare
Synedra vaucheriae	Rare	--	--
S. undulata	Rare	--	--
Thalassionema			
nitzschioides	--	Rare	Common
Thalassiothrix			
frauenfeldii	--	Rare	Common
T. longissima	--	--	Common
Thalassiothrix sp.	--	--	Common
Unidentified pennate	Dominant	--	Common
Unidentified centric	Rare	--	--
Total number			
Diatom species	34	10	25

Phytoplankton	Hawaii	Gulf	Puerto Rico
Dinoflagellates	Rank	Rank	Rank
Amphidinium sp.	--	--	Rare
Ceratium fusus	Rare	--	--
C. incisum	Rare	--	--
C. karsteni	Rare	--	--
C. pentagonum	Rare	Rare	--
C. setaceum	Rare	--	--
Ceratium sp.	--	--	Rare
Cochlodinium sp.	Common	--	--
Dinophysis exigua	Rare	--	--
Dinophysis sp.	--	--	Rare
Exuviella apora	Rare	--	--
E. baltica	Rare	--	Common
E. compressa	Rare	Common	--
E. vaginula	--	Rare	--
Exuviella sp.	--	Common	Rare
Goniaulax sp.	Rare	--	Rare
Gymnodinium sp.	Rare	--	Rare
Gyrodinium sp.	Rare	--	--
Ornithocercus			
quadratus	--	Rare	--
Oxytoxum gigas	Rare	--	--
O. variabile	Rare	--	--
Parahistioneis sp.	--	--	Rare
Peridinium globulus	Rare	--	--
P. hirobus	Rare	--	--
P. pendunculatum	--	Common	Rare
P. tube	Rare	--	--
Peridinium sp.	Rare	--	Rare
Phalacroma ovum	Rare	--	--
Podolampas bipes	Rare	--	--
P. elegans	Rare	--	--
P. palmipes	Rare	Rare	--
Podolampas sp.	Rare	--	--
Pronoctiluca			
pelagica	--	--	Rare
Prorocentrum			
lebourae	Rare	--	--
P. micans	--	Common	--
Prorocentrum sp.	--	--	Rare
Protoerythroptosis			
crassicaudata	Rare	--	--
Pyrocystis			
fusiformis	Rare	--	--
P. hamulus var.			
semicircularis	Rare	--	--
P. lunula	Rare	--	--
P. pseudonociluca	Rare	--	--
P. robusta	Rare	--	--
Unidentified			
athcate dino-			
flagellates	Dominant	--	Common
Total number			
Dinoflagellate species	33	9	14

Phytoplankton	Hawaii	Gulf	Puerto Rico
Blue-green Algae	Rank	Rank	Rank
Trichodesmium sp.	Rare	--	Dominant

Silicoflagellates	Rank	Rank	Rank
Dictyocha fibula	Rare	--	--
Ebria sp.	Rare	--	--

Coccolithophroids	Rank	Rank	Rank
Discosphaera			
tubifer	Rare	--	--
Gephyrocapsa			
psamosa	Rare	--	--
Rhabdosphaera sp.	Rare	--	--
Umbellosphaera sp.	Common	--	--
Unidentified cocco-			
lithophorida	Common	--	Rare
Total number			
coccolitho-			
phorid species	5	0	1

TABLE 6. The natural range of phytoplankton density off Kahe Point, Oahu, based on the benchmark survey effort. The values represent 95% confidence limits for the depth-integrated parameters over the photic zone at two locations and over the area as a whole (from Noda et al. 1981b).

Parameter	Natural range at P = 0.05		
	Station 1	Station 2	Kahe Point
Chlorophyll-a ($\text{mg} \cdot \text{m}^{-2}$)	17.60-25.02	15.38-21.58	17.59-22.21
Phaeopigments ($\text{mg} \cdot \text{m}^{-2}$)	11.09-23.92	10.50-29.38	13.35-24.03
ATP ($\text{mg} \cdot \text{m}^{-2}$)	4.25-4.91	3.81-4.56	4.13-4.37
Photosynthesis ($\text{mg C} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$)	6.53-15.54	10.73-22.35	10.23-17.35

TABLE 7. Criteria for detection of significant environmental change, based on a single benchmark data set. Detection limits (DL) given by $DL = t_{0.05}[(S_1^2 + S_2^2)/2]^{1/2}$, where S_1^2 and S_2^2 are the mean square values for each source of variation at Stations 1 and 2, respectively (from Noda et al. 1981b).

Parameter	Level under examination	Source level for criteria	Detection limit at $P = 0.05$
Chlorophyll- <u>a</u>	Subsamples	Analytical	0.03 $\mu\text{g} \cdot \text{l}^{-1}$
	Hydrocasts	Subsamples	0.31 $\mu\text{g} \cdot \text{l}^{-1}$
	Stations	Hydrocasts	0.64 $\mu\text{g} \cdot \text{l}^{-1}$
	Time	Hydrocasts	0.93 $\mu\text{g} \cdot \text{l}^{-1}$
Phaeopigments	Subsamples	Analytical	0.03 $\mu\text{g} \cdot \text{l}^{-1}$
	Hydrocasts	Subsamples	0.25 $\mu\text{g} \cdot \text{l}^{-1}$
	Stations	Hydrocasts	0.54 $\mu\text{g} \cdot \text{l}^{-1}$
	Time	Hydrocasts	2.54 $\mu\text{g} \cdot \text{l}^{-1}$
ATP	Subsamples	Analytical	0.25 $\text{ng} \cdot \text{l}^{-1}$
	Hydrocasts	Subsamples	13.92 $\text{ng} \cdot \text{l}^{-1}$
	Stations	Hydrocasts	16.64 $\text{ng} \cdot \text{l}^{-1}$
	Time	Hydrocasts	100.68 $\text{ng} \cdot \text{l}^{-1}$
Photosynthesis	Hydrocasts	Subsamples	0.16 $\mu\text{g C} \cdot \text{l}^{-1} \cdot \text{h}^{-1}$
	Stations	Hydrocasts	1.11 $\mu\text{g C} \cdot \text{l}^{-1} \cdot \text{h}^{-1}$
	Time	Hydrocasts	1.69 $\mu\text{g C} \cdot \text{l}^{-1} \cdot \text{h}^{-1}$

TABLE 8. Comparison of phytoplankton parameters off Kahe Point (O'OTEC) and Keahole Point (HOTEC). The O'OTEC and HOTEC surveys included six cruises each and were conducted between May 1980-May 1981 and October 1978-December 1979, respectively. The upper limit of integration was 135 m (O'OTEC) and 250 m (HOTEC) for the biomass data, and 135 m (O'OTEC) and 120 m (HOTEC) for the photosynthetic data. The variation factor gives the ratio of the maximum/minimum range value, and the coefficient of variation ($10^2 \cdot \text{s.d.}/\bar{X}$) is given in units of percent (from Noda et al. 1981b).

Comparison	Site	Phytoplankton Parameters			
		Chlorophyll. a ($\text{mg} \cdot \text{m}^{-2}$)	Phaeopigments ($\text{mg} \cdot \text{m}^{-2}$)	ATP ($\text{mg} \cdot \text{m}^{-2}$)	Photosynthesis ($\text{mg C} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$)
Annual Range	O'OTEC	14.18 - 30.58	6.51 - 60.04	3.03 - 5.27	3.02 - 36.64
	HOTEC	14.64 - 44.45	4.07 - 15.07	0.84 - 5.58	0.72 - 18.70
Variation Factor	O'OTEC	2.2	9.2	1.7	12.1
	HOTEC	3.0	4.4	6.6	26.0
Annual Mean	O'OTEC	19.90	18.69	4.37	13.79
	HOTEC	24.56	11.81	3.06	8.79
Coefficient of Variation	O'OTEC	35	86	17	77
	HOTEC	43	54	59	89
Number of Hydrocasts	O'OTEC	36	36	36	36
	HOTEC	12	12	12	12

TABLE 9. Summary of conclusion drawn with respect to comparison of phytoplankton parameters of the Keahole and Kahe environments.

Comparison	Conclusions
Chlorophyll <u>a</u> biomass	Similar at both sites; less overall temporal variation at Kahe.
Phaeopigment concentrations	At Kahe, higher in upper mixed layer and at subsurface maxima than at Keahole; depth of phaeopigment maximum corresponded with depth of chlorophyll maximum; pattern of temporal variability uniform with noteworthy increase only in August; degree of temporal variability 2.4X (excluding August); no significant relationship with primary production. At Keahole, depth of phaeopigment maximum deeper than chlorophyll maximum; phaeopigment stock showed considerable variability throughout year; temporal variability 4.4X; significant relationship found with primary production.
Phaeopigment: Chlorophyll <u>a</u> ratio	Higher at Kahe in mixed layer and at maximum.
Total microbial biomass	Higher at Kahe; mean ATP concentrations higher at Kahe in upper 100 m and in photic zone; total microbial biomass varied by a factor of 1.7 throughout year at Kahe but considerable variation experienced at Keahole; ATP concentrations highest from August to January at Kahe, erratic temporal variation over 14 months at Keahole with occasional extreme low values.
Photosynthetic rates	Greater at Kahe; pattern of variability showed less variability at Kahe. At Keahole, rates showed 26-fold variation; erratic changes throughout year, and extremely low production on occasions.

TABLE 10. Half-saturation constants (K_L) in terms of total irradiance during the incubation period, for the reference (non-enriched) carbon fixation profiles. The mean ($\pm$ s.d.) K_L value from these trials was $3.86 \pm 1.19 \times 10^{20}$ quanta $\cdot$ m $^{-2}$; the mean ($\pm$ s.d.) depth at which these values occurred was 40 ± 13 m (from Bienfang and Szyper 1982).

Experiment No.	Total irradiance at 1-2 m		Depth of K_L (m)
	depth during incubation (10^{20} quanta $\cdot$ cm $^{-2}$)	K_L (10^{20} quanta $\cdot$ cm $^{-2}$)	
1	26.2	3.78	61
2	11.4	3.56	37
3	11.4	3.56	37
5	9.4	2.62	40
6	10.0	5.47	24

TABLE 11. Biomass measures of zooplankton samples obtained during the HOTECH-12 plume survey including statistical tests of difference between means (from Noda et al. 1981c).

	Sample No.	Dry weight (mg/m ³)	Ash-free dry weight (mg/m ³)	Percent ash (%)
In plume	PSB1	3.30	2.23	33
	PSB2	3.65	2.21	39
	PSB3	2.94	2.01	32
	PSB4	3.71	2.31	38
	Mean $\bar{X}_p$	3.40	2.19	35.5
	s.d. S_x	0.36	0.12	7.5
Out of plume	OPB1	4.86	3.69	25
	OPB2	5.27	3.91	26
	OPB3	5.37	4.20	22
	OPB4	5.99	4.72	21
	Mean $\bar{X}_o$	5.37	4.12	23.5
	s.d. S_x	0.47	0.47	2.4
Statistical tests				
	$\bar{X}_o - \bar{X}_p$	1.97	1.93	-12
	t_{bdf}	6.71	*	-5.66
	P (2 tailed)	<0.001	0.014	<0.01

*Variances were heterogeneous, P calculated by Fisher's exact probability test.

TABLE 12. Macrozooplankton standing stocks as dry weight in mg/m² from daytime and nighttime bongo net profiles, each value being an integrated amount from 0 to 200, 200 to 1,000, or 0 to 1,000 m. Data are given for profiles at each station from Sites A, B, and C in 1975 and 1976. The ratios of these integrated stocks at night to that for the day (N/D ratio) are shown for each profile, and the dashes indicate no data (from Hirota 1977).

Depth	Site A							
	A-30° N Profile		A+00° N Profile			A+30° N Profile		
	1	2	1	2	3	1	2	
1975								
Day								
0-200 m	942	1054	960	913	1262	681	809	
200-1000 m	795	958	934	880	613	415	-	
0-1000 m	1737	2012	1894	1793	1875	1096	-	
Night								
0-200 m	864	639	2553	-	1086	1872	1634	
200-1000 m	531	548	607	516	-	-	-	
0-1000 m	1395	1187	3160	-	-	-	-	
N/D 1000 m ratio	0.80	0.59	1.67	-	-	-	-	
N/D 200 m ratio	0.92	0.61	2.66	-	0.86	2.75	2.02	
1976								
Day								
0-200 m	1880	2111	2051	2332	3943	781	842	
200-1000 m	540	388	904	521	1658	576	496	
0-1000 m	2420	2499	2955	2853	5601	1357	1338	
Night								
0-200 m	2386	3109	3669	3167	4766	1437	1415	
200-1000 m	295	377	396	443	629	444	465	
0-1000 m	2681	3486	4065	3610	5396	1881	1880	

TABLE 12. Continued.

Depth	Site B									
	B-30° N Profile		B+0° N Profile				B+0° N Profile			
	1	2	1	2	3	4	1	2	3	4
<u>1975</u>										
Day										
0-200 m	1514	1236	2494	2627	2330	2553	956	843		
200-1000 m	-	-	1210	1376	1196	954	-	-		
0-1000 m	-	-	3704	4003	3126	3507	-	-		
Night										
0-200 m	2981	2824	4089	5154	-	3311	1046	1101		
200-1000 m	847	2141	1244	948	1268	940	-	-		
0-1000 m	3828	4965	5333	6102	-	4251	-	-		
N/D 1000 m ratio	-	-	1.44	1.52	-	1.21	-	-		
N/D 200 m ratio	1.97	2.28	1.64	1.96	-	1.30	1.09	1.31		
<u>1976</u>										
Day										
0-200 m	-	2900	3421	2448	2839	2614	2853	2650		
200-1000 m	-	-	1687	1143	1033	755	1351	996		
0-1000 m	-	-	5108	3591	3872	3369	4204	3646		
Night										
0-200 m	2790	2469	2920	2979	4252	3699	4172	4498		
200-1000 m	520	-	1309	1354	1262	525	990	737		
0-1000 m	3310	-	4229	4333	5514	4224	5162	5235		
N/D 1000 m ratio	-	-	0.83	1.21	1.42	1.25	1.23	1.44		
N/D 200 m ratio	-	0.85	0.85	1.22	1.50	1.42	1.46	1.70		

TABLE 12. Continued.

Depth	Site C									
	C-30° N Profile		C+0° N Profile		C+30° N Profile					
	1	2	1	2	3	4	1	2	3	4
<u>1975</u>										
Day										
0-200 m	2035	1653	792	-	1624	1733	-	-	-	-
200-1000 m	1105	1126	-	-	663	910	859	813	-	-
0-1000 m	3140	2779	-	-	2287	2643	-	-	-	-
Night										
0-200 m	1898	2005	1902	1843	1303	1586	-	-	-	-
200-1000 m	824	771	-	-	378	587	-	-	-	-
0-1000 m	2722	2776	-	-	1681	2173	-	-	-	-
N/D 1000 m ratio	0.87	1.00	-	-	0.74	0.82	-	-	-	-
N/D 200 m ratio	0.93	1.21	2.40	-	0.80	0.92	-	-	-	-
<u>1976</u>										
Day										
0-200 m	7210	-	794	696	-	932	1577	1175	-	-
200-1000 m	-	-	566	387	915	436	-	-	-	-
0-1000 m	-	-	1360	1083	-	1368	-	-	-	-
0-200 m	-	5572	1538	1545	-	-	1967	1968	-	-
200-1000 m	-	-	111	123	298	246	-	-	-	-
0-1000 m	-	-	1649	1668	-	-	-	-	-	-
N/D 1000 m ratio	-	-	1.21	1.54	-	-	-	-	-	-
N/D 200 m ratio	-	-	1.94	2.22	-	-	1.25	1.67	-	-

TABLE 13. Zooplankton biomass in O'OTEC samples. All biomass values in mg/m^3 (from Noda et al. 1981b).

CRUISE 1
25-27 May 1980

Sample ID	Dry weight	Ash-free dry weight	% ash
1D25 A	4.67	3.05	35
1D25 B	3.31	1.80	46
1D200 A	3.88	2.58	34
1D200 B	2.70	1.63	40
1D600 A	1.35	1.00	26
1D1000 A	0.39	0.21	46
1N25 A	5.29	2.93	45

TABLE 14. Zooplankton biomass in O'OTEC samples. All biomass values in mg/m^3 (from Noda et al. 1981b).

CRUISE 2
10-11 August 1980

Sample ID	Dry Weight	Ash-free Dry Weight	% Ash	Carbon	Nitrogen	C:N Ratio	Carbon: Ash-free Ratio
1D25 A	10.6	5.34	50				
1D25 B	9.01	5.54	39	2.55	0.600	4.2	0.46
1D200 B	3.27	1.99	39				
1D600 A	2.03	1.49	27	0.71	0.160	4.4	0.48
1D1000 A	1.05	0.51	51				
1N25 A	5.24	3.11	41				
1N25 B	3.48	2.25	35				
1N200 A	4.69	3.14	33				
1N200 B	3.72	2.73	27	1.04	0.240	4.3	0.38
1N600 A	0.54	0.36	33	0.17	0.038	4.5	0.47
2DNeu A	9.82	3.79	61	1.58	0.320	4.9	0.42
2D25 A	5.35	3.06	43				
2D25 B	6.08	3.07	50				
2D200 A	3.68	2.25	39	1.10	0.270	4.1	0.49
2D200 B	3.10	1.88	39				
2D600 A	0.81	0.58	28				
2D1000 A	0.41	0.21	49	0.10	0.019	5.3	0.48
2N25 A	16.7	9.84	41	4.51	0.990	4.6	0.46
2N25 B	15.8	9.17	42				
2N200 A	4.71	2.94	38				

TABLE 15. Zooplankton biomass in O'TEC samples. All biomass values in mg/m^3 (from Noda et al. 1981b).

CRUISE 3
5-6 November 1980

Sample ID	Dry Weight	Ash-free Dry Weight	% Ash	Carbon	Nitrogen	C:N Ratio	Carbon: Ash-free Ratio
1DNeu A	7.51	3.74	50				
1DNeu B	11.3	5.41	52	2.40	0.470	5.1	0.44
1D25 A	16.2	8.64	47				
1D25 B	19.3	10.4	46				
1D200 A	1.38	0.96	30				
1D200 B	2.72	1.56	43	0.70	0.160	4.4	0.45
1D600 A	1.21	0.81	33				
1D1000 A	0.63	0.42	33	0.21	0.044	4.9	0.51
1NNeu A	9.36	5.78	38				
1N25 A	15.6	9.61	38				
1N25 B	22.5	13.8	39	6.02	1.34	4.5	0.44
1N200 A	4.72	3.37	29				
1N200 B	4.13	3.02	27				
2DNeu A	4.58	1.72	62				
2DNeu B	6.52	2.39	63				
2D25 A	5.69	3.35	41	1.57	0.340	4.6	0.47
2D25 B	4.03	2.10	48				
2D200 A	3.87	2.78	28				
2D200 B	3.89	2.57	34				
2D600 A	1.14	0.89	22	0.42	0.100	4.2	0.47
2D1000 A	0.57	0.40	30				
2NNeu A	9.63	3.74	61	1.63	0.350	4.7	0.44
2NNeu B	3.55	2.21	38				
2N25 A	20.0	12.1	40				
2N25 B	14.0	9.96	29				
2N200 A	5.58	3.84	31	1.93	0.450	4.3	0.50
2N200 B	5.13	3.85	25				
2N600 A	2.18	1.79	18	0.78	0.190	4.1	0.44

TABLE 16. Zooplankton biomass in O'TEC samples. All biomass values in mg/m^3 (from Noda et al. 1981b).

CRUISE 4
10-11 January 1981

Sample ID	Dry Weight	Ash-free Dry Weight	% Ash	Carbon	Nitrogen	C:N Ratio	Carbon: Ash-free Ratio
1DNeu A	7.32	5.59	24				
1DNeu B	7.30	5.74	21				
1D25 A	5.67	3.75	34				
1D25 B	4.23	3.02	29	1.39	0.330	4.2	0.46
1D200 A	3.88	2.80	28				
1D200 B	3.35	2.27	32				
1D600 A	0.80	0.56	30				
1D600 B	0.82	0.65	21	0.33	0.068	4.9	0.51
1D1000 A	0.35	0.25	29	0.12	0.025	4.8	0.48
1NNeu A	38.8	25.0	36				
1NNeu B	28.0	20.2	28	10.3	2.07	5.0	0.51
1N25 A	12.0	9.43	21				
1N25 B	15.0	11.5	24				
1N200 A	2.33	1.80	23				
1N200 B	2.86	2.14	25	1.02	0.250	4.1	0.48
1N600 A	0.76	0.58	24				
2DNeu A	10.9	7.45	32	3.28	0.730	4.5	0.44
2DNeu B	10.2	6.84	33				
2D25 A	3.70	2.82	24				
2D25 B	4.61	3.42	26				
2D200 A	3.42	2.66	22				
2D200 B	3.58	2.74	23				
2D600 A	0.64	0.51	20				
2D600 B	0.64	0.48	25				
2D1000 A	0.18	0.14	22				
2NNeu A	11.1	8.18	26				
2NNeu B	13.7	9.14	33				
2N25 A	15.0	11.0	27	5.11	1.16	4.4	0.46
2N25 B	14.3	10.0	30				
2N200 A	5.31	4.19	21				
2N200 B	7.93	5.89	26				
2N600 A	0.92	0.66	28	0.32	0.069	4.6	0.48

TABLE 17. Zooplankton biomass in O'TEC samples. All biomass values in mg/m^3 (from Noda et al. 1981b).

CRUISE 5
10-11 March 1981

Sample ID	Dry Weight	Ash-free Dry Weight	% Ash	Carbon	Nitrogen	C:N Ratio	Carbon: Ash-free Ratio
1DNeu A	3.24	2.22	31	1.25	0.230	5.4	0.56
1DNeu B	2.05	1.26	39				
1D25 A	3.59	1.61	55				
1D25 B	2.43	1.43	41				
1D200 A	1.13	0.89	21	0.40	0.096	4.2	0.46
1D200 B	3.44	2.64	23				
1D600 A	2.30	1.73	25				
1D600 B	1.84	1.41	23				
1D1000 B	0.43	0.34	21	0.18	0.032	5.6	0.53
1NNeu A	12.5	5.92	53				
1NNeu B	14.3	8.46	41				
1N25 A	8.32	4.65	44	2.02	0.480	4.2	0.43
1N25 B	7.72	4.47	42				
1N200 A	6.66	5.19	22				
1N200 B	5.10	3.82	25				
1N600 A	0.69	0.52	25	0.25	0.055	4.5	0.48
2DNeu A	1.76	0.63	64				
2DNeu B	1.22	0.45	63				
2D25 A	1.41	0.94	33				
2D25 B	1.83	1.11	39	0.50	0.110	4.5	0.45
2D200 A	4.20	3.21	24				
2D200 B	3.29	2.56	22				
2D600 A	1.58	1.21	23				
2D600 B	1.83	1.50	18	0.75	0.180	4.2	0.50
2D1000 A	1.07	0.87	19				
2NNeu A	12.5	5.61	55				
2NNeu B	10.7	5.31	50	2.32	0.480	4.8	0.44
2N25 A	6.66	4.73	29				
2N25 B	5.03	4.17	17				
2N200 A	8.48	6.55	23				
2N200 B	5.98	4.73	21	2.21	0.570	3.9	0.47
2N600 A	0.23	0.18	22				

TABLE 18. Zooplankton biomass in O'TEC samples. All biomass values in mg/m^3 (from Noda et al. 1981b).CRUISE 6
27-28 May 1981

Sample ID	Dry Weight	Ash-free Dry Weight	% Ash	Carbon	Nitrogen	C:N Ratio	Carbon: Ash-free Ratio
1DNeu A	3.32	2.60	22				
1DNeu B	4.65	3.59	23				
1D25 A	4.20	3.24	23				
1D25 B	3.19	2.29	28	1.11	0.250	4.4	0.48
1D200 A	3.70	2.90	22				
1D200 B	3.14	2.46	22				
1D600 A	1.82	1.45	20	0.70	0.160	4.4	0.48
1D600 B	1.48	1.16	22				
1D1000 A	0.72	0.60	17				
1NNeu A	12.9	8.63	33	4.15	0.940	4.4	0.48
1NNeu B	13.7	9.22	33				
1N25 A	14.1	10.2	28				
1N25 B	18.0	12.6	30				
1N200 A	7.96	6.33	20	3.04	0.750	4.1	0.48
1N200 B	9.03	6.94	24				
1N600 A	0.93	0.70	22				
2DNeu A	2.18	1.29	41	0.65	0.087	7.4	0.50
2DNeu B	3.21	1.72	46				
2D25 A	5.05	3.45	32				
2D25 B	7.42	5.57	25				
2D200 B	3.98	2.95	26	1.38	0.340	4.1	0.47
2D600 A	0.63	0.45	29				
2D600 B	1.13	0.89	21				
2D1000 A	0.49	0.40	18	0.23	0.038	6.0	0.57
2NNeu A	12.6	7.45	41				
2NNeu B	16.3	11.2	31				
2N25 A	22.5	16.9	25				
2N25 B	15.9	12.2	23	5.94	1.47	4.0	0.49
2N200-A	7.19	5.47	24				
2N200 B	6.05	4.58	24				
2N600 A	0.88	0.67	24	0.34	0.078	4.4	0.51

TABLE 19. List of fishes at Keahole and Kahe Points and the annual mean catch and value as derived from catch reports of the Hawaii Division of Aquatic Resources, 1976-80.

Scientific name	English name	Local name	Keahole Point			Kahe Point		
			Catch (kg)	Value (\$)	Catch (kg)	Value (\$)	Catch (kg)	Value (\$)
Thunnidae	Tunas	--	40	38	1	1	1	1
<u>Katsuwonus pelamis</u>	Skipjack tuna	Aku	28,098	42,422	164,058	215,755	164,058	215,755
<u>Thunnus albacares</u>	Yellowfin tuna	Ahi	385,865	1,002,672	14,899	40,490	14,899	40,490
<u>Thunnus alalunga</u>	Albacore	Ahipalaha	3,332	5,520	5	17	5	17
<u>Thunnus thynnus</u>	Bluefin tuna	Maguro	5,193	19,136	--	--	--	--
<u>Thunnus obesus</u>	Bigeye tuna	Ahi, menpachi	9,305	39,373	132	795	132	795
<u>Euthynnus affinis</u>	Kawakawa	Kawakawa	999	1,567	553	562	553	562
Istiophoridae	Pillfishes	Au	6	7	--	--	--	--
<u>Tetrapturus audax</u>	Striped marlin	Au, naraigi	14,830	18,015	2,297	4,658	2,297	4,658
<u>Makaira nigricans</u>	Blue marlin	Au, kajiki	97,475	66,893	8,106	13,533	8,106	13,533
<u>Xiphias gladius</u>	Swordfish	Au ku	2,122	6,291	2	4	2	4
<u>Istiophorus</u>	Sailfish	Au lepe	312	389	11	--	11	--
platypterus								
<u>Coryphaena hippurus</u>	Dolphin	Mahimahi	14,421	54,228	3,339	16,502	3,339	16,502
<u>Acanthocybium</u>	Wahoo	Ono	29,021	79,969	965	3,295	965	3,295
<u>solandri</u>								
<u>Epinephelus quernus</u>	Sea bass	Hapuupuu	899	2,516	40	138	40	138
<u>Seriola dumerili</u>	Greater amberjack	Kahala	6,159	8,451	223	357	223	357
<u>Pristipomoides</u>	Pink snapper	Kalekale	966	3,008	36	115	36	115
<u>sieboldii</u>								
<u>Caranx melampygus</u>	Blue crevally	Omilu	20	51	109	299	109	299
<u>Pristipomoides</u>	Pink snapper	Opakapaka	12,490	55,651	382	1,904	382	1,904
<u>filamentosus</u>								
<u>Apiron virescens</u>	Gray snapper	Uku	6,541	25,446	156	524	156	524
<u>Etelis carbunculus</u>	Red snapper	Ehu	1,438	5,939	67	356	67	356
<u>Etelis coruscans</u>	Red snapper	Onaga	4,426	20,172	67	377	67	377
Carangidae	Jacks	Ulua	5,315	12,956	1,137	3,462	1,137	3,462
<u>Mulloidichthys</u>	Red goatfish	Weke ulu	1,505	5,642	1,033	3,057	1,033	3,057
<u>auriflamma</u>								
<u>Bodianus bilunulatus</u>	Spot wrasse	Aawa	151	103	10	9	10	9
<u>Acanthurus achilles</u>	Achilles tang	Pakuikui	8	9	--	--	--	--
<u>Acanthurus dussumieri</u>	Surgeonfish	Palani	378	368	526	453	526	453

TABLE 19. Continued.

Scientific name	English name	Local name	Keahole Point		Kahe Point	
			Catch (kg)	Value (\$)	Catch (kg)	Value (\$)
Scaridae	Parrotfish	Panuhunuhu	23	27	1	1
Scaridae	Parrotfish	Panunu	15	25	49	96
Gnathanodon speciosus	Yellow jack	Paopao	7	5	1	1
Myripristis chryseres	Squirrelfish	Pauu	112	294	--	--
Acanthurus xanthopterus	Surgeonfish	Pualu	238	308	188	173
Muraenidae	Eel	Puhi	20	24	262	96
Muraenidae	Black eel	Puhi-black	--	--	3	2
Conger cinereus	White eel	Tohe	9	18	63	35
Scaridae	Parrotfish	Uhu	739	1,436	137	236
Pristipomoides zonatus	Brigham's snapper	Gindai	144	428	9	36
Neomysis chaptalii	False mullet	Uouea	198	736	1	1
Apogon kallopterus	Cardinalfish	Upapalu	95	195	--	--
Myripristis spp.	Squirrelfish	Uu, menpachi	3,916	13,490	315	1,254
Holocentridae	Squirrelfish	Ukanipo	36	27	1	1
Ruvettus pretiosus	Oilfish	Walu	6	1	3	2
Mulloidichthys samoensis	Goatfish	Weke	406	1,430	1,371	2,134
Alectis ciliaris	Threadfin jack	Ulua kihikihi	5	10	1	1
Lampris regius	Moonfish	--	1	1	2	7
Tetrapturus angustirostris	Shortbill spearfish	--	2,789	4,330	235	512
Makaira indica	Black marlin	Au	1,365	1,102	115	204
Parupeneus pleurostigma	Goatfish	Malu	6	18	71	179
Exocoetidae	Flyingfish	Malolo	1	1	--	--
Abudefduf abdominalis	Damselfish	Mamamo	19	50	175	430
Acanthurus sandvicensis	Convict tang	Marini	665	1,714	67	155
Elasmobranch	Shark	Mano	572	409	8	2
Sphyrna lewini	Hammerhead shark	Mano kihikihi	22	--	11	7
Etruneus micropus	Round herring	Makiawa	1	1	8	9

TABLE 19. Continued.

Scientific name	English name	Local name	Keahole Point		Kahe Point	
			Catch (kg)	Value (\$)	Catch (kg)	Value (\$)
<u>Parupeneus multifasciatus</u>	Goatfish	Koano	765	3,353	46	179
<u>Polydactylus sexfilis</u>	Threadfin	Moi	114	656	4	16
<u>Mulloidichthys pflugeri</u>	Red goatfish	Moilua	1	1	1	1
<u>Monotaxis grandoculis</u>	Porgy	Mu	40	141	98	340
<u>Acanthurus olivaceus</u>	Orange spot tang	Naenae	47	76	130	99
<u>Kyphosus bigibbus</u>	Rudderfish	Nenu	181	241	49	61
<u>Scorpaenopsis cacopsis</u> and <u>S. gibbosa</u>	Scorpionfish	Nohu	364	1,110	34	153
<u>Aulostomus chinensis</u>	Trumpetfish	Nunu	5	7	3	3
<u>Alutera scripta</u>	Filefish	Oililepe	--	--	226	429
<u>Albula vulpes</u>	Bonefish	Oio	77	92	948	2,025
<u>Caranx mate</u>	Jack	Omaka	3	16	2	6
<u>Arothron hispidus</u>	Balloonfish	Copuhue	--	--	45	3
<u>Decapterus macarellus</u>	Mackerel scad	Opelu	143,605	325,061	948	2,310
<u>Anampses cvuieri</u>	Spotted wrasse	Cpule	--	--	3	7
<u>Zebrasoma flavescens</u>	Yellow tang	Pala	2	6	--	--
<u>Bothus mancus</u> and <u>B. pantherines</u>	Flounder	Pakii	3	5	3	2
Belonidae	Needlefish	Ahaaha	3	2	5	7
<u>Kuhlia sandvicensis</u>	Mountain bass	Aholehole	49	206	44	181
<u>Selar crumenophthalmus</u>	Bigeye scad	Akule	6,914	12,669	6,887	17,422
<u>Selar crumenophthalmus</u>	Small bigeye scad	Fahalalu	858	1,300	3,435	7,798
Holocentridae	Squirrelfish	Alaibe	259	805	5	12
<u>Mugil cephalus</u>	Mullet	Anaama	101	456	47	252
<u>Chanos chanos</u>	Milkfish	Awa	251	338	243	614
<u>Elops hawaiiensis</u>	Ten pounder	Aweawa	1	1	29	60
Priacanthidae	Red bigeye	Aweoweo	1,399	3,438	42	100
Labridae	Wrasses	Fa	1	1	1	1
Scaridae	Parrotfish	Hanui	132	313	2	3
<u>Gempylus serpens</u>	Snake mackerel	Hauliuli	149	240	--	--

TABLE 19. Continued.

Scientific name	English name	Local name	Keahole Point		Kahe Point	
			Catch (kg)	Value (\$)	Catch (kg)	Value (\$)
<u>Scyllarides</u>	Slipper lobster	Ulapapapa	2	--	6	23
<u>squamosus</u> and						
<u>S. haani</u>						
Octopoda	Octopus	Hee, tako	136	633	344	1,078
Decapoda	Squid	Muhee	109	177	--	--
<u>Helcioniscus exaratus</u>	Limpet	Opihi	598	2,502	--	--
and <u>H. argentatus</u>						
<u>Centrechinus</u>	Sea urchin	Wana	--	--	1	--
<u>paucispinus</u>						
Holothuridae	Sea cucumber	Namako	1	2	30	183
Rhodophyta and	Seaweed	Limu	--	--	1,220	2,118
Chlorophyta						
Miscellaneous	--	--	2,147	5,614	145	247
Total			807,914	1,882,450	219,510	353,853

TABLE 20. Marine mammals of the Gulf of Mexico and Hawaii (from Payne 1979).

Species	Gulf of Mexico	Hawaii	Species	Gulf of Mexico	Hawaii
Order Sirenia			<i>Grampus griseus</i> ,	Rare	Rare
Family Trichechidae			Risso's dolphin		
* <i>Trichechus manatus</i> ,	common inshore	—	<i>Lagenodelphis ho-</i>	—	Rare
West Indian manatee			sei, Shortsnouted		
			whitebelly dolphin		
Order Carnivora,			<i>Orcinus orca</i> ,	Rare	—
Suborder Pinnipedia			Killer whale		
Family Phocidae			<i>Peponocephala</i>	—	Rare
* <i>Monachus shauins-</i>	—	Common	<i>electra</i> , Little		
landi, Hawaiian		away from	blackfish		
monk seal		OTEC sites	<i>Pseudorca crassi-</i>	Fairly common	Fairly
* <i>M. tropicalus</i> ,			dens, False		common
Caribbean monk seal	extinct?	—	killer whale		
Family Otariidae			<i>Stenella attenuata</i> ,	—	Fairly
<i>Zalophus californi-</i>	Rare, introduced	—	Spotted dolphin		common
nianus, Californi-			<i>S. coeruleoalba</i>	Fairly common	Fairly
a sea lion			(= <i>S. styx</i>),		common
			Striped dolphin		
Order Cetacea,			<i>S. frontalis</i> (= <i>S.</i>	Fairly common	—
Suborder Mysticeti			<i>claytoni</i> , Bridled		
Family Balaenidae			dolphin		
* <i>Balaena glacialis</i> ,	Rare	—	<i>S. longirostris</i> ,	Rare	Common
Black Right whale			Spinner dolphin		
Family Balaenop-			<i>S. plagiodon</i> ,	Common	Rare
teridae			Spotted dolphin		
<i>Balaenoptera acu-</i>	Rare	—	<i>Steno bredanensis</i> ,	Rare	Rare
torostrata,			Roughtoothed		
Minke whale			Dolphin		
<i>B. borealis</i> ,	Rare	—	<i>Tursiops gilli</i> ,	—	Fairly
Sei whale			Pacific bottle-		common
<i>B. edeni</i> ,	Rare	Occasional	nosed dolphin		
Bryde's whale			<i>Tursiops truncatus</i> ,	Common	Fairly
* <i>B. musculus</i> ,	Rare	?	Bottlenosed		common
Blue whale			dolphin		
* <i>B. physalus</i> ,	Rare	?	Family Physeteridae		
Fin whale			<i>Kogia breviceps</i> ,	Common inshore	Rare
* <i>Megaptera novae-</i>			Pygmy sperm whale	in western Gulf	
<i>angliae</i> ,			<i>K. simus</i> , Dwarf	Rare	Rare
Humpback whale	—	—	sperm whale		
Suborder Odontoceti			* <i>Physeter catodon</i> ,	Fairly common in	Occasional
Family Delphinidae			Sperm whale	past, now rare	*
<i>Delphinus delphis</i> ,	Fairly common	Fairly	Family Ziphiidae		
Common dolphin		common†	<i>Mesoplodon densi-</i>	—	Rare
<i>Feresa attenuata</i> ,	Rare	Fairly	<i>rostris</i> , Dense-		
Pygmy killer whale		common	beak whale		
<i>Globicephala macro-</i>	Rare	Rare	<i>M. europaeus</i> ,	Rare	—
<i>rhyncus</i> , Short-			Gulfstream		
finned pilot whale			beaked whale		
			<i>Ziphius caviros-</i>	Rare	Rare
			<i>tris</i> , Goose-		
			beak whale		

*Denotes endangered or threatened species.

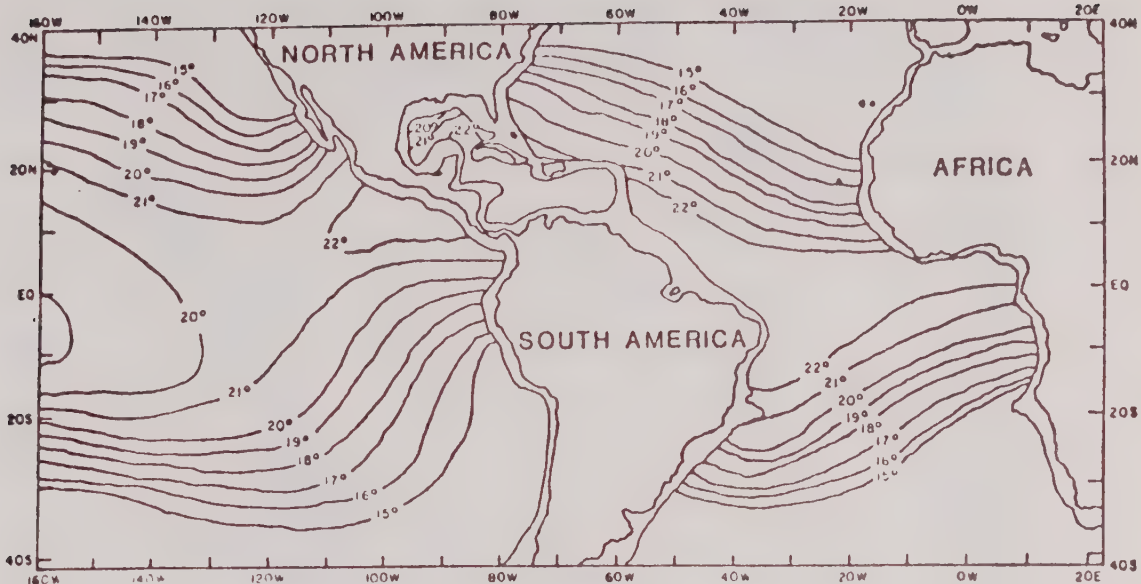


Figure 1.--The OTEC thermal resource-- ΔT ($^{\circ}\text{C}$) between surface and 1,000 m depth (from Yuen 1981).

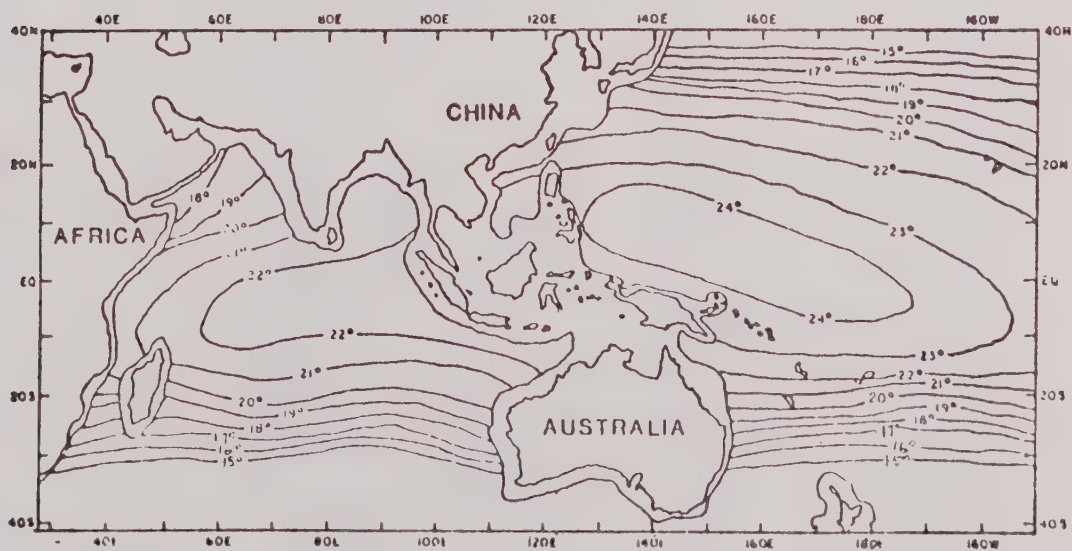


Figure 2.--The OTEC thermal resource-- ΔT ($^{\circ}\text{C}$) between surface and 1,000 m depth (from Yuen 1981).

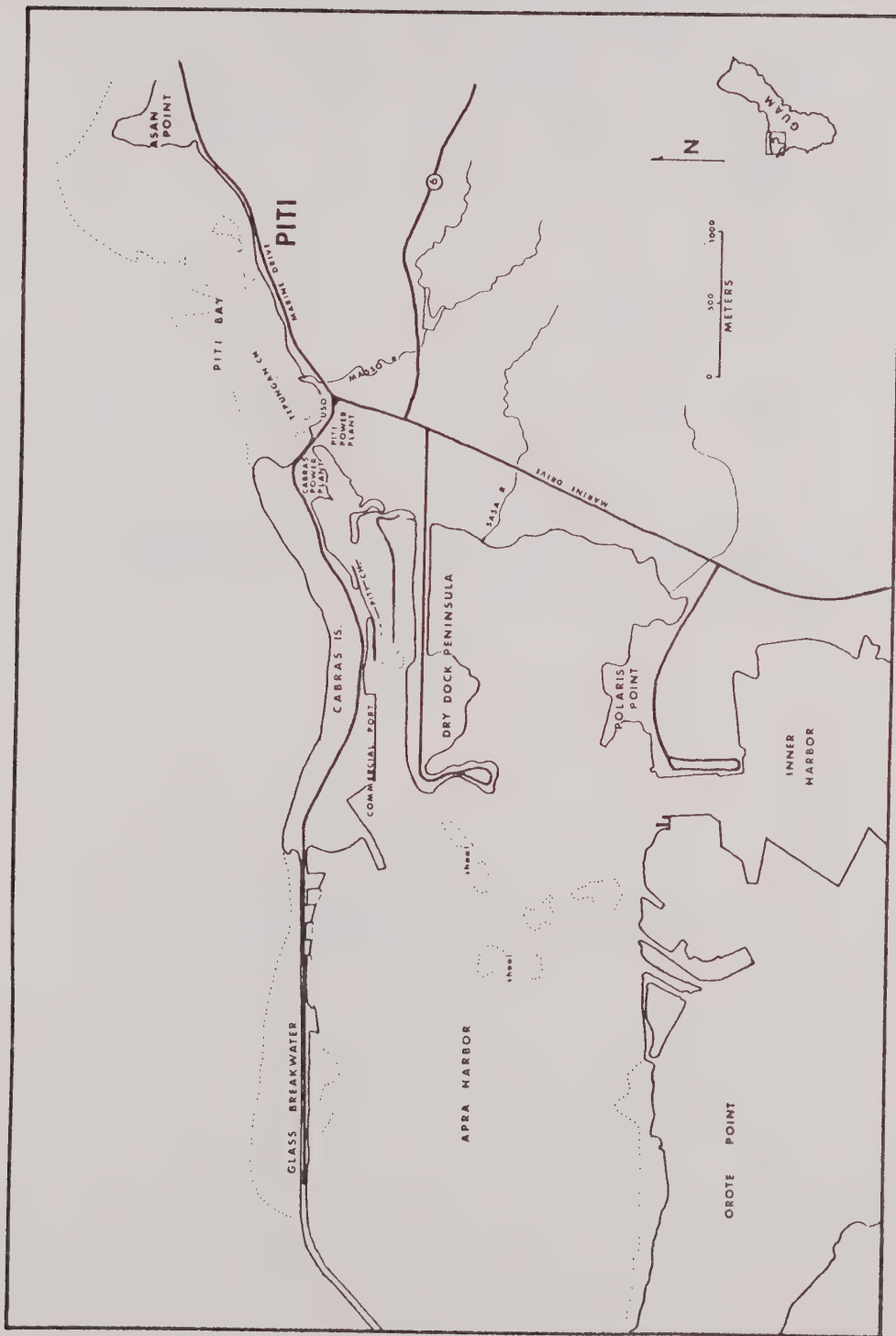


Figure 4.--Geographic setting of study area for potential OTEC development on Guam (map adapted from Marsh and Doty 1976).

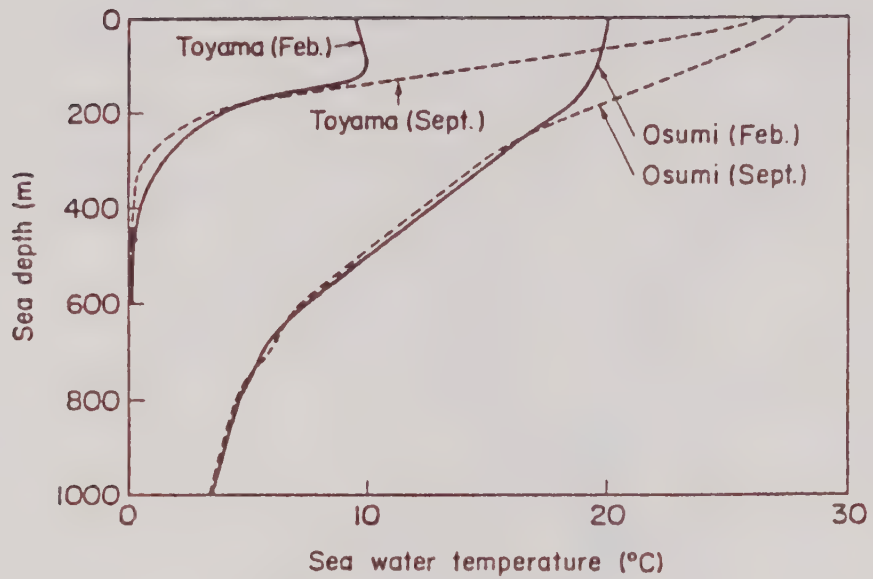


Figure 5.--Maximum (Sept.) and minimum (Feb.) of monthly average of sea temperature at offshore of Osumi Island (Pacific Ocean) Toyama Bay (Japan Sea) (Homma and Kamogawa 1979).

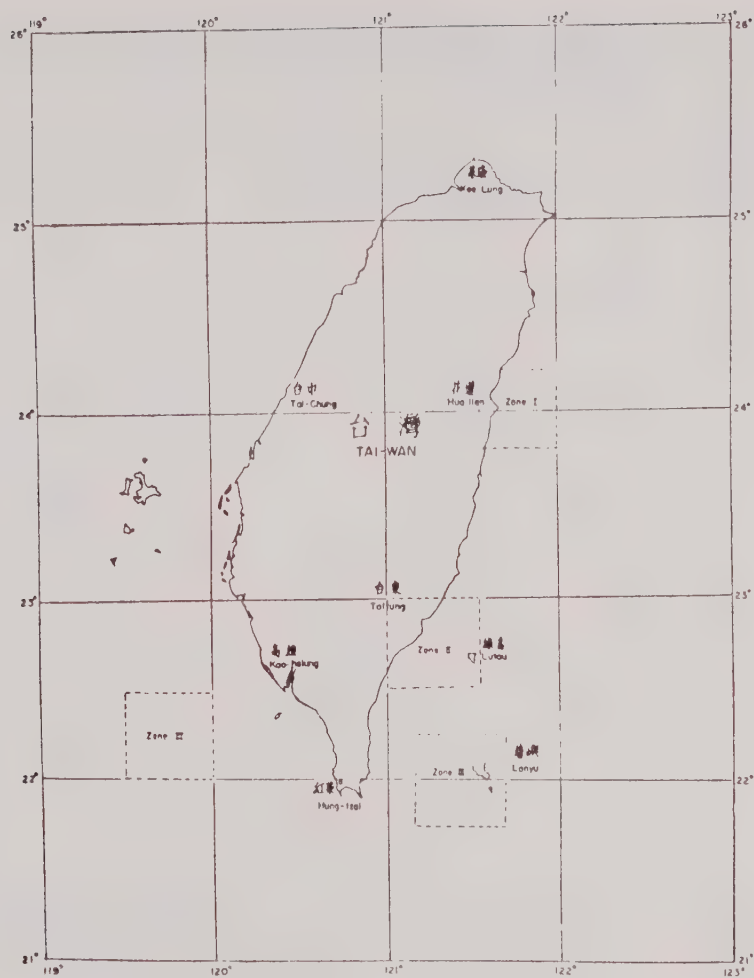


Figure 6.--Geographic setting of study area for potential OTEC development on Taiwan (Liang et al. 1981).

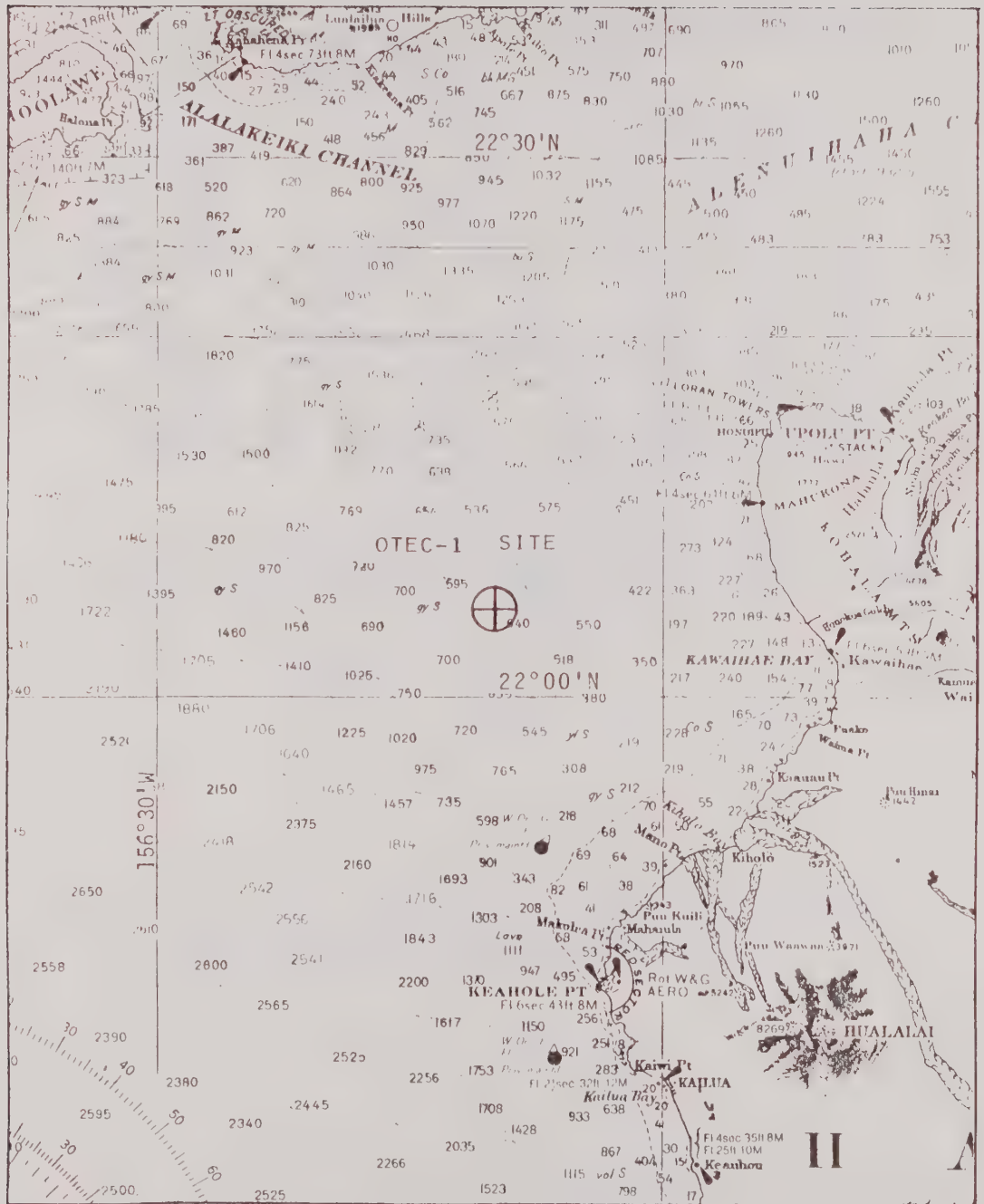


Figure 7.--The OTEC-1 site location off Keahole Point, Hawaii.
(from Noda et al. 1981b).

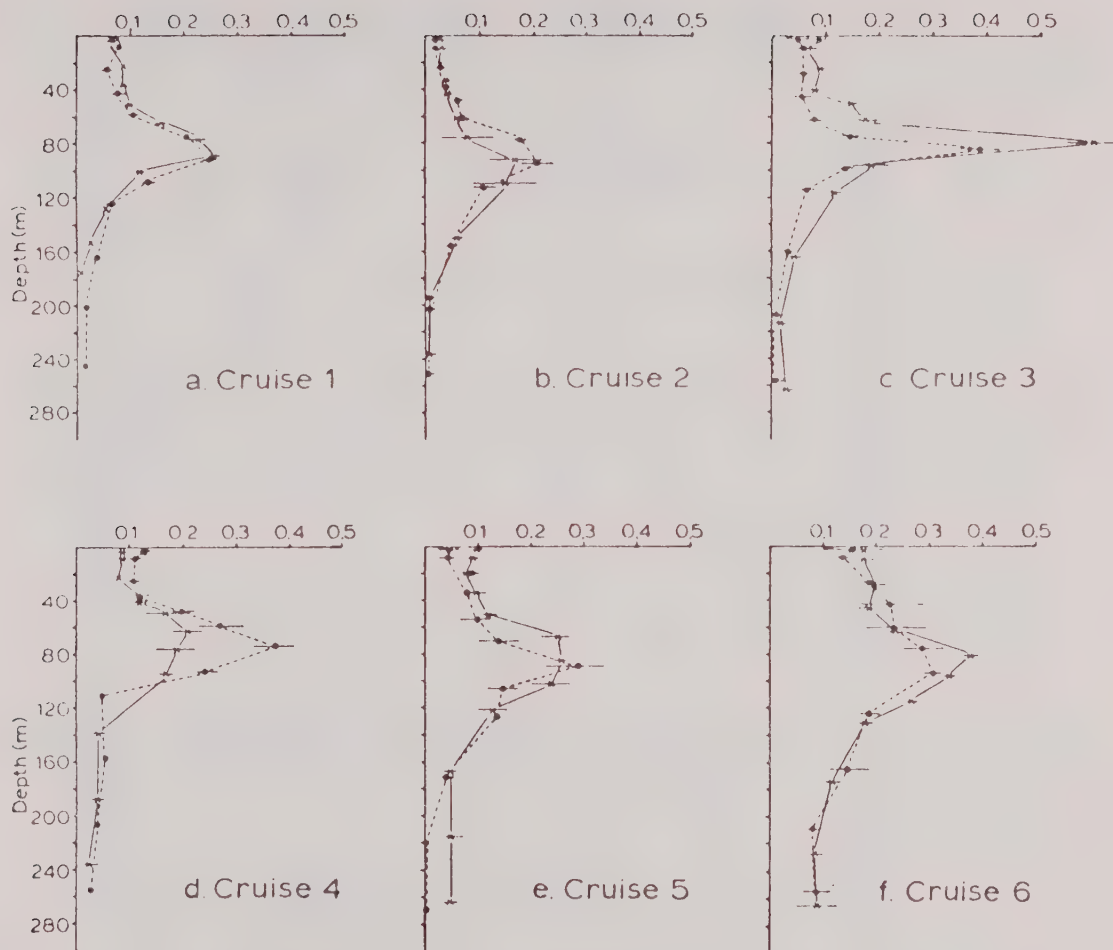


Figure 8.--Vertical profiles of chlorophyll *a* concentrations ($\text{mg}\cdot\text{m}^{-3}$) in the water column at the HOTECH site. The "dawn" hydrocasts are represented by the dotted-line plots, and "dusk" hydrocasts by the solid-line plots. The horizontal bars indicate the standard deviations about the means of triplicate analyses (Noda et al. 1980).

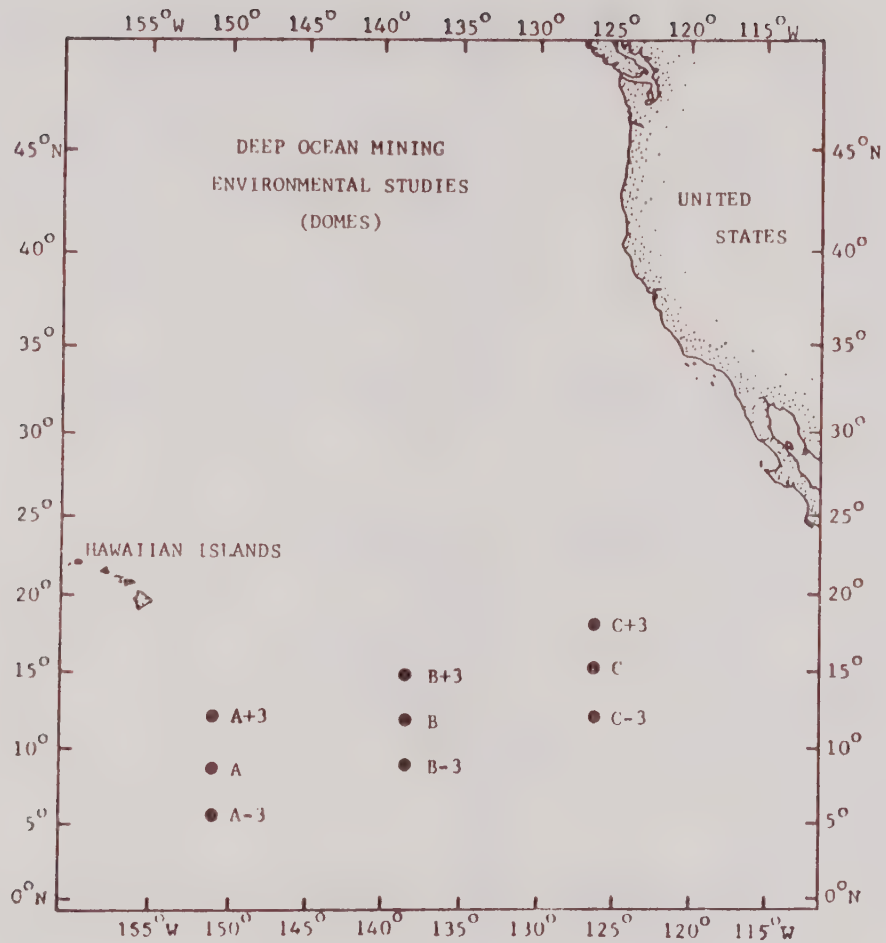


Figure 9.--Stations with discrete water samples analyzed quantitatively in this study from collections made in fall (1975) and spring (1976) (Fryxell et al. 1979).

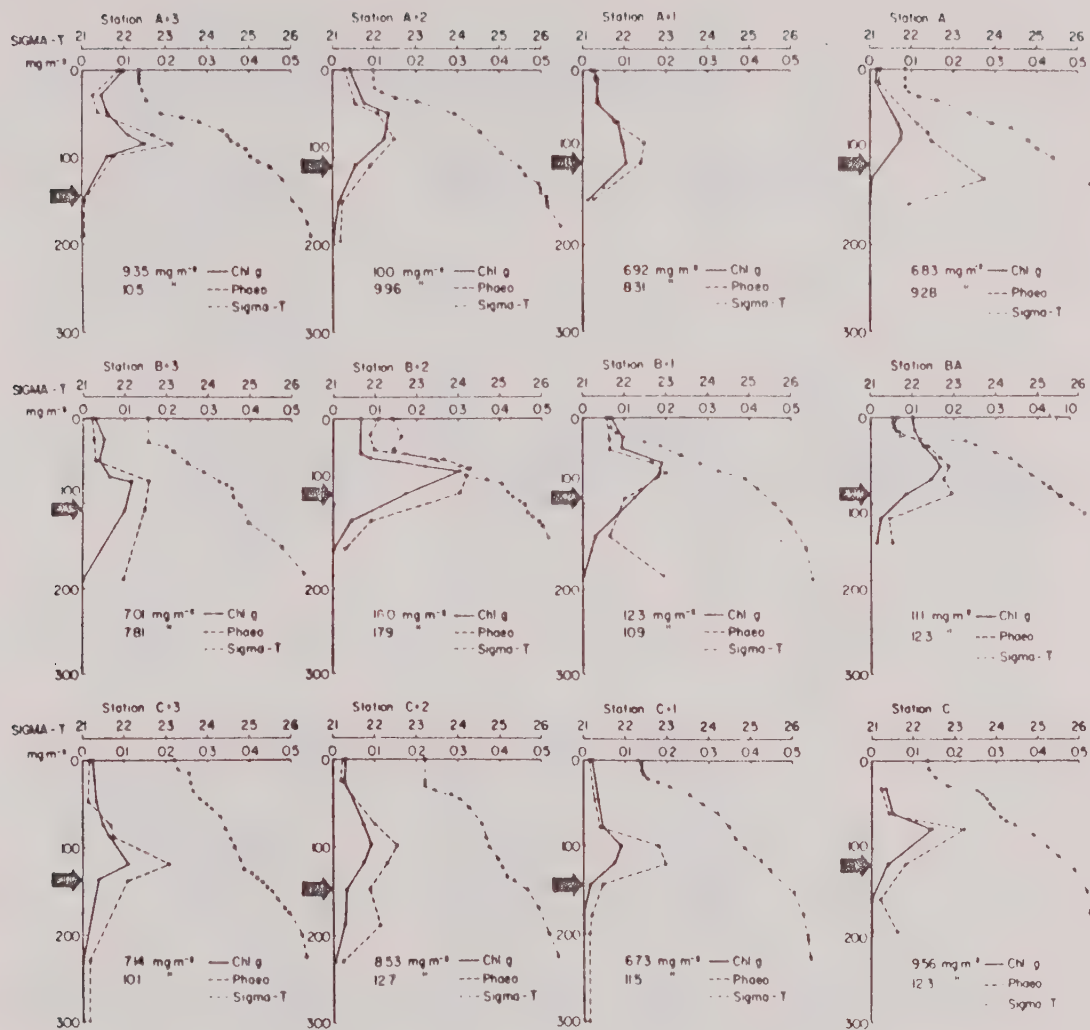


Figure 10.--Vertical distribution of chlorophyll a and phaeopigments concentrations with sigma-t at the stations occupied in the three transects A, B, and C in the summer of 1975. Depth (m) of the euphotic zone is shown by arrows (El-Sayed and Taguchi 1979).

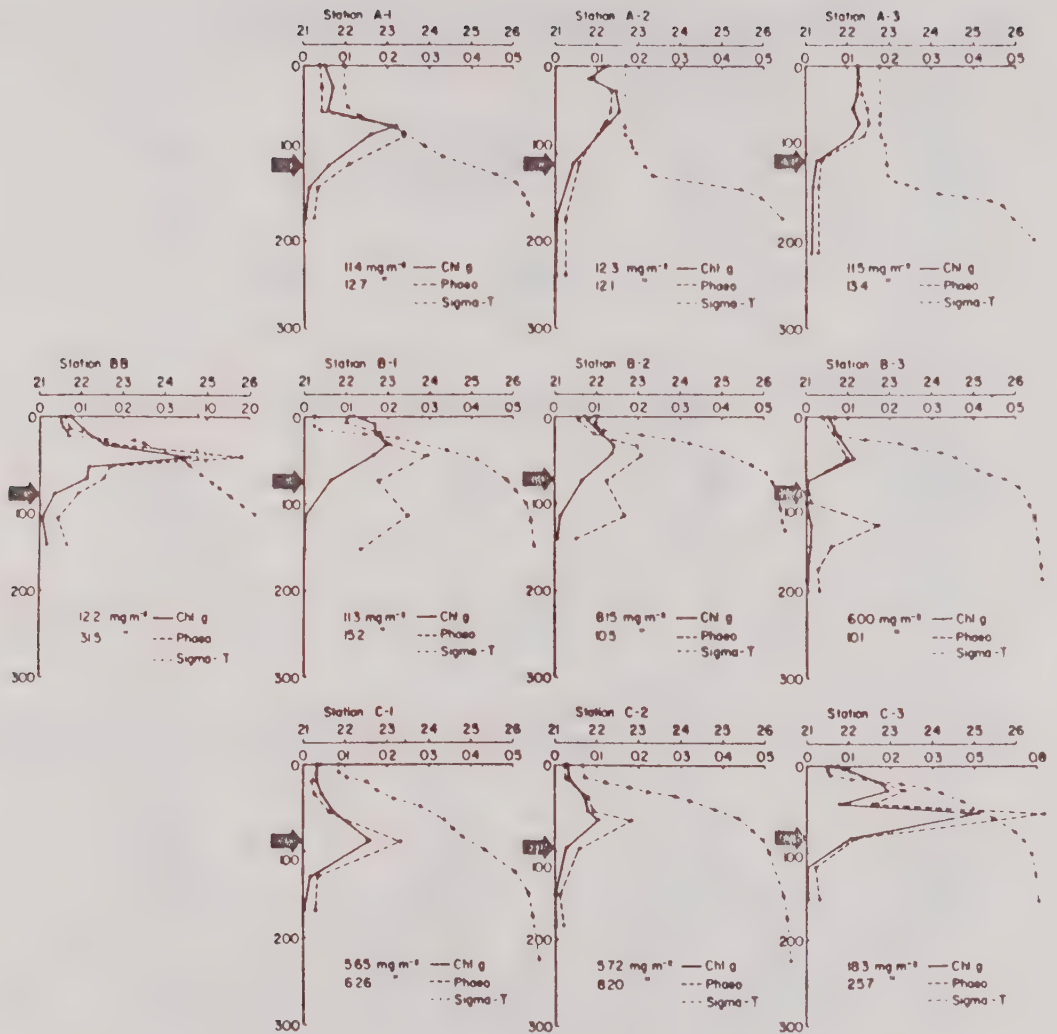


Figure 10.--Continued.

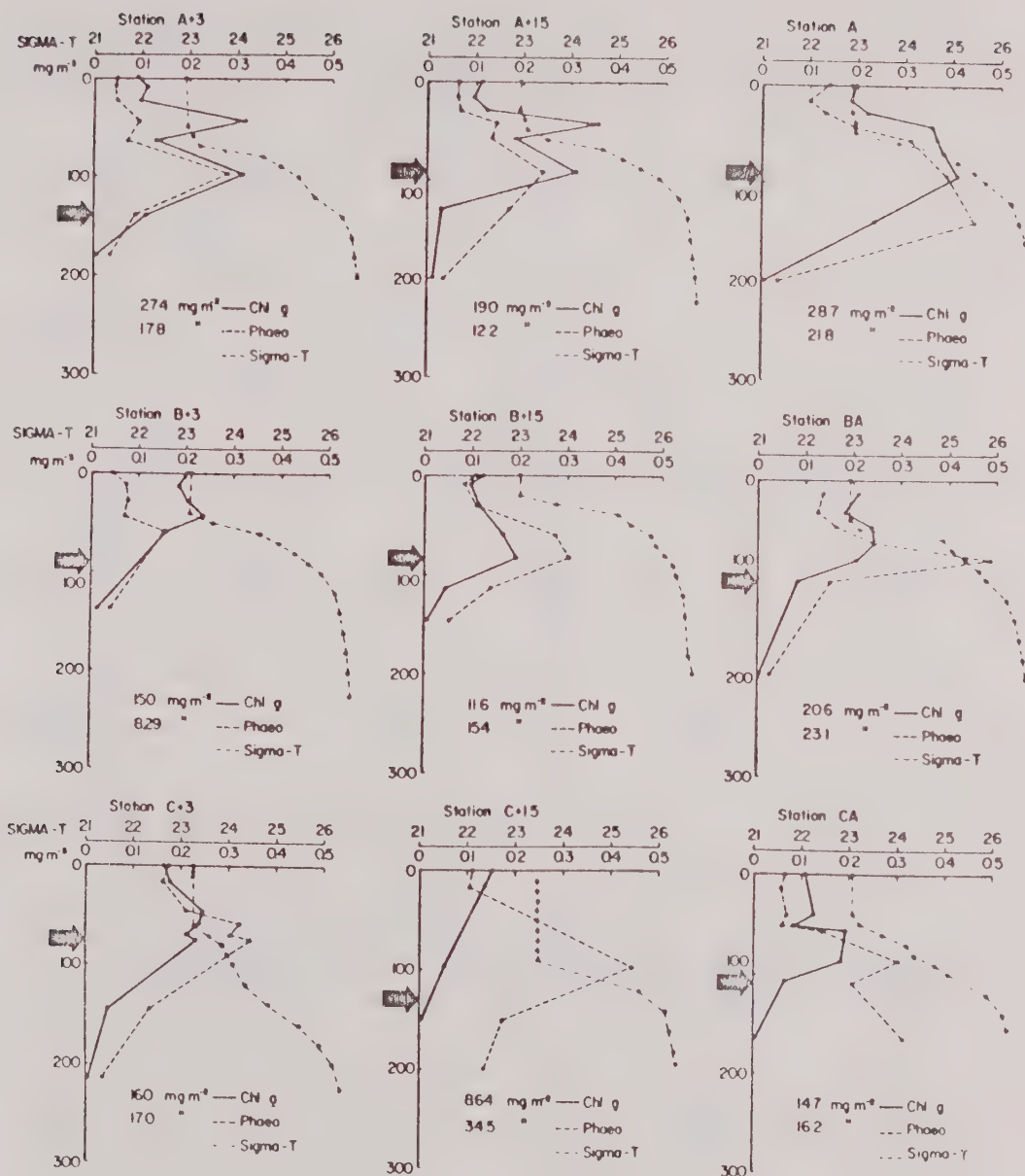


Figure 11.--Vertical distribution of chlorophyll *a* and phaeopigments concentrations with sigma-t at the stations occupied in the three transects A, B, and C in the winter of 1976. Depth (m) of the euphotic zone is shown by arrows (El-Sayed and Taguchi 1979).

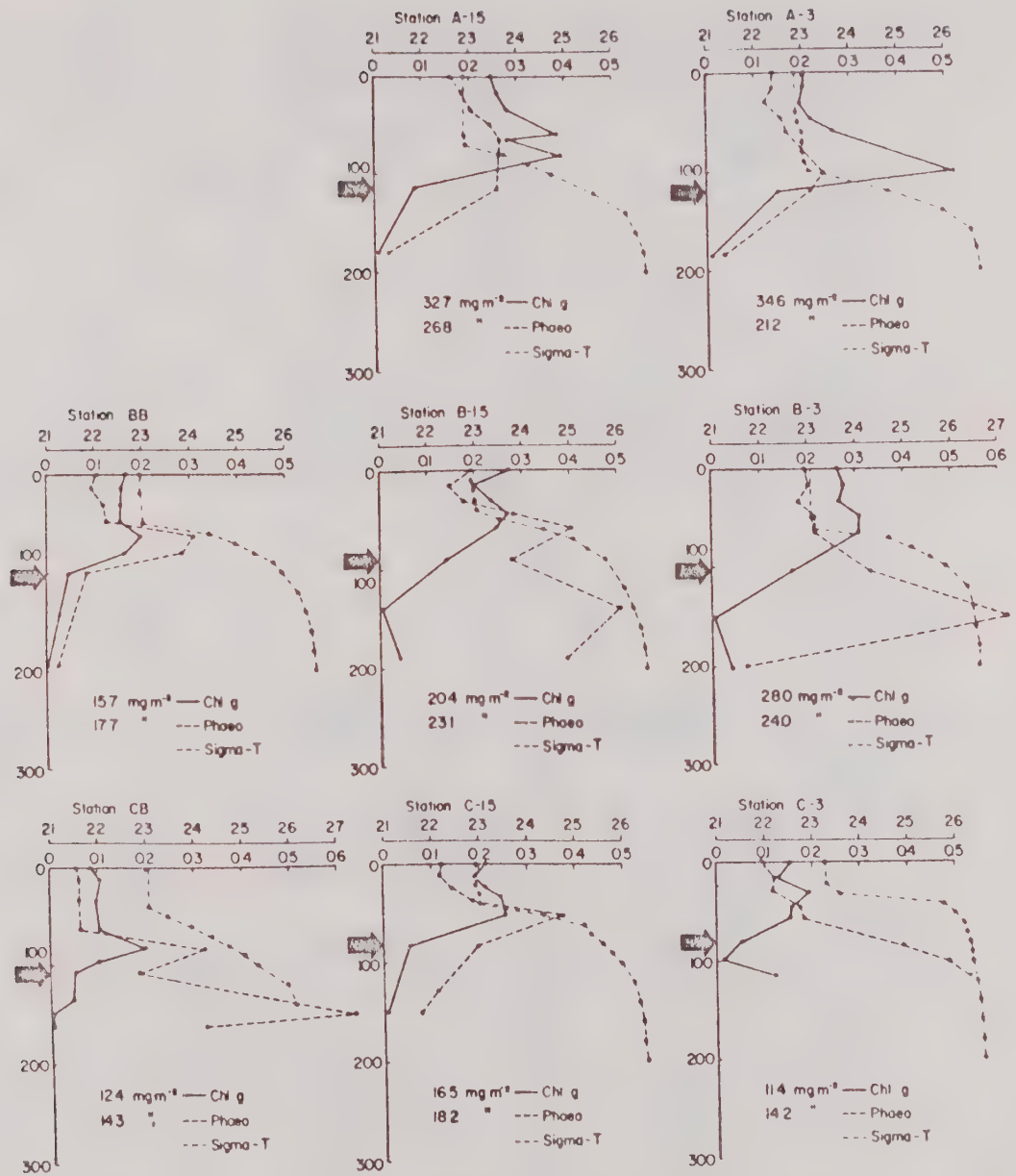


Figure 11.--Continued.

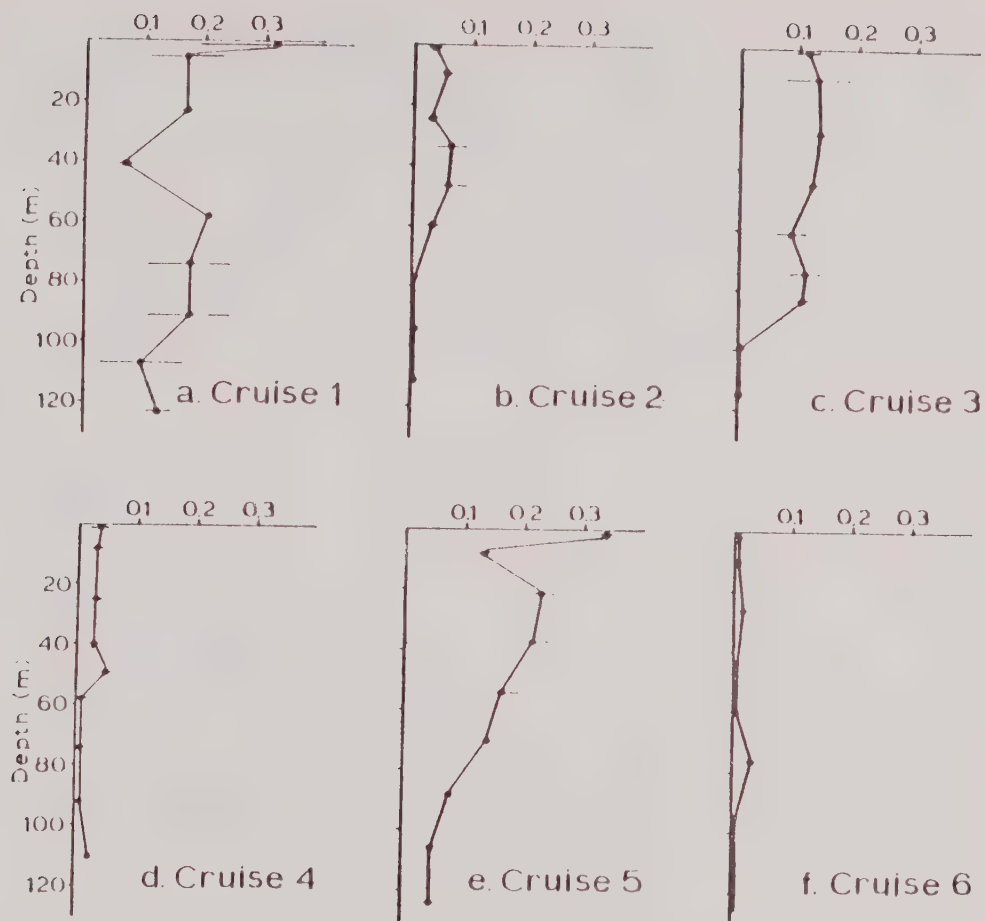


Figure 12.--Vertical profiles of the rates of primary production ($\text{mg C}\cdot\text{m}^{-3}\cdot\text{h}^{-1}$) at the HOTECH site. The horizontal bars indicate the standard deviations about the means of triplicate analyses (Noda et al. 1980).

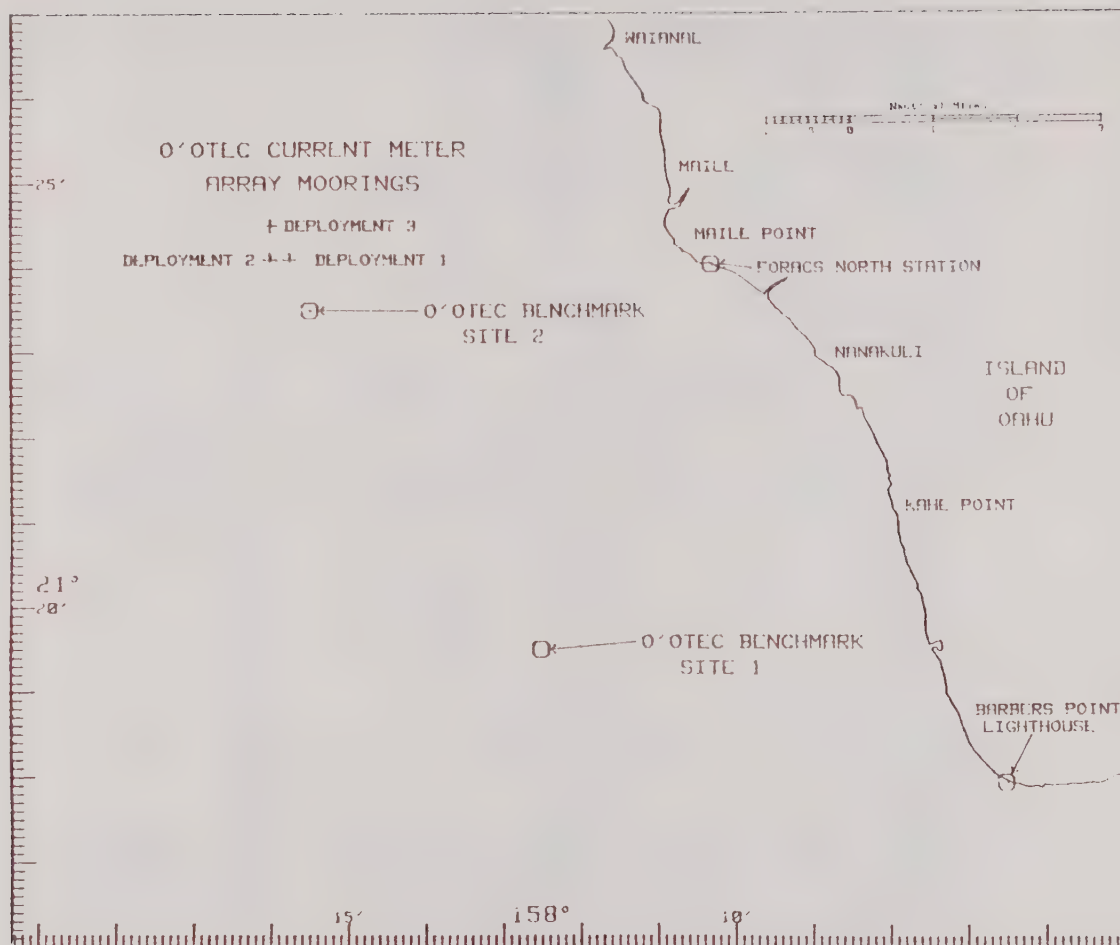


Figure 13.--Kahe Point, Oahu OTEC benchmark and current meter mooring sites, designated the O'OTEC sites (Noda et al. 1981b).

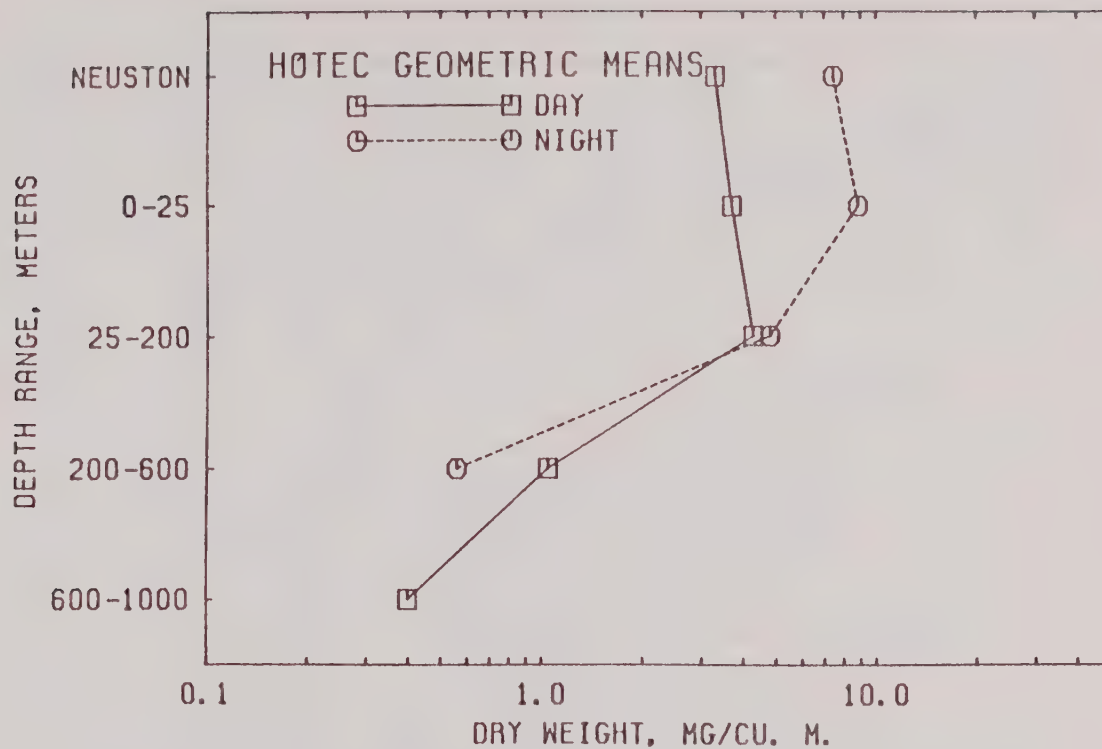


Figure 14.--Geometric means of zooplankton dry weight versus depth for HOTEK cruises 11 and 12, day and night (Noda et al. 1981a).

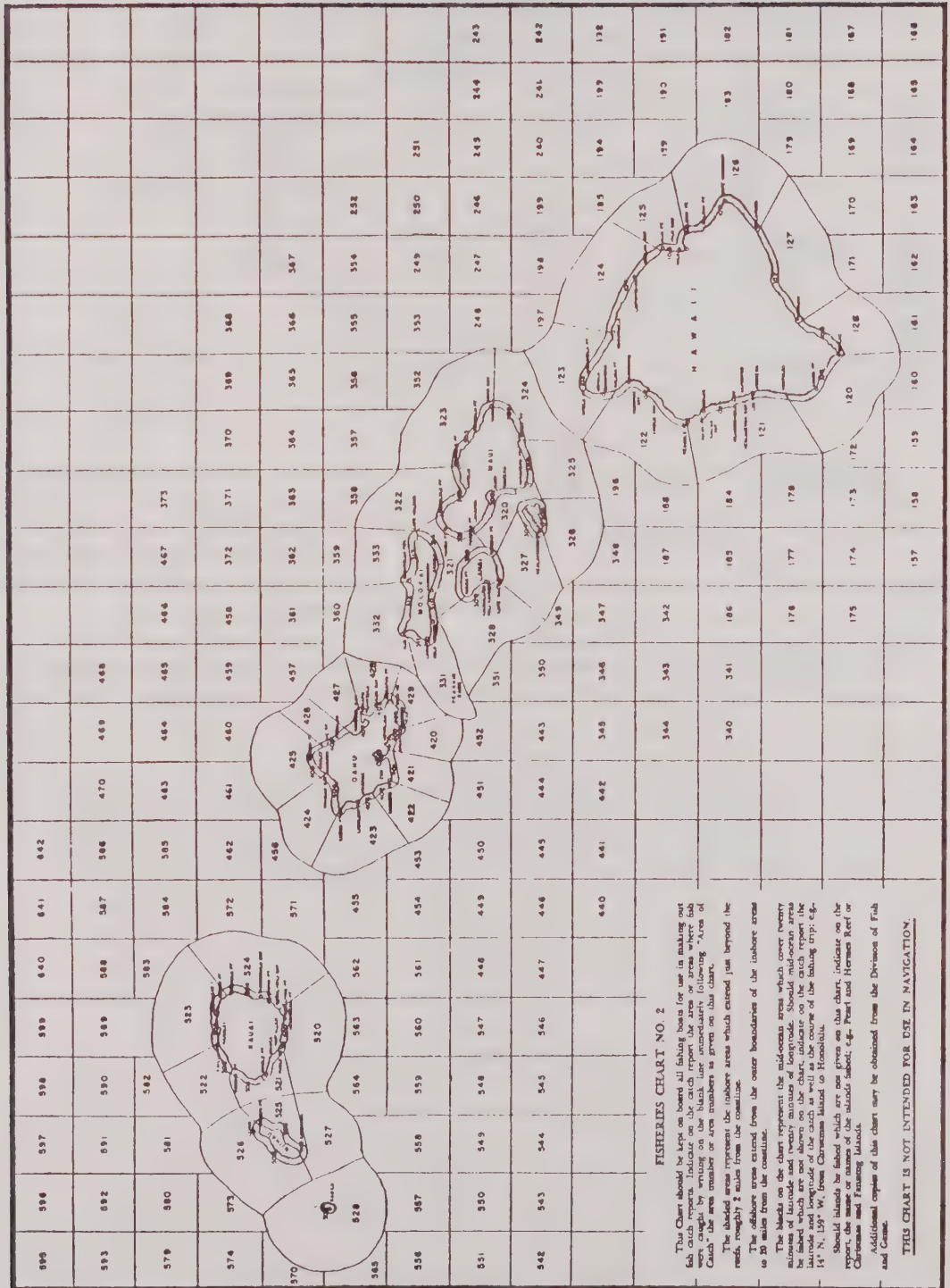


Figure 15.--Fisheries Chart No. 2.

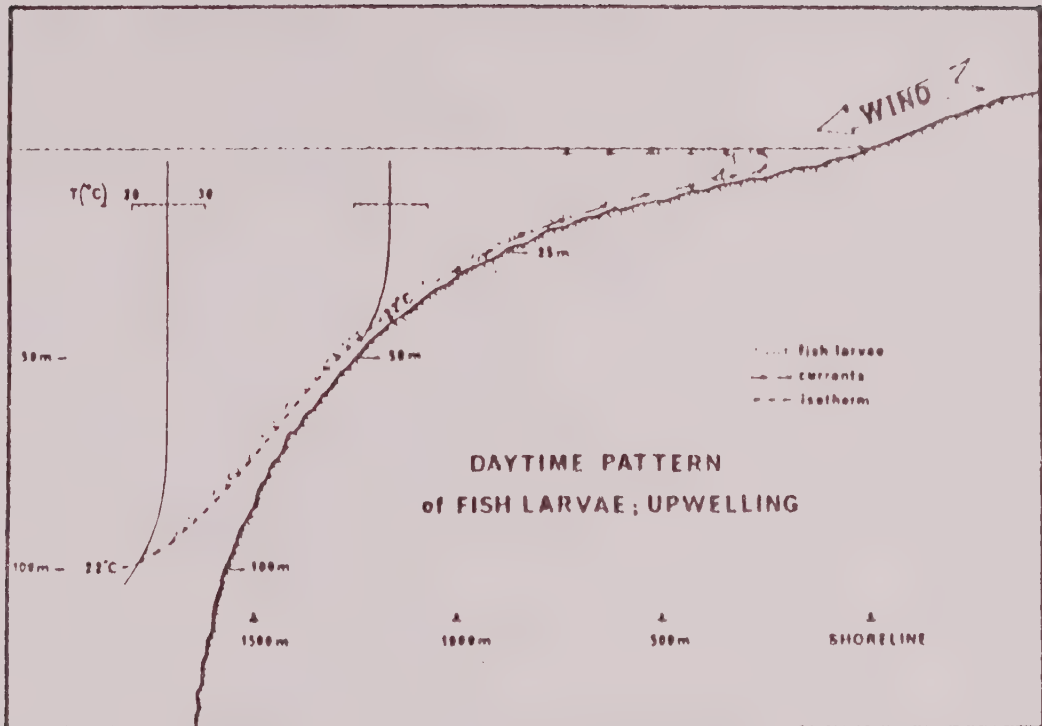


Figure 16.--Hypothetical daytime patterns of fish larvae off Kahe Point, Oahu, during upwelling. Temperature profiles from BT records 15 March 1974, 1500-1530 h H.S.T. Abcissal numbers are distances (m) from shoreline (Miller 1979).

THE KEWALO RESEARCH FACILITY

1958 TO 1983--25 YEARS OF PROGRESS

RANDOLPH K. C. CHANG, RICHARD W. BRILL, and HOWARD O. YOSHIDA

Southwest Fisheries Center Honolulu Laboratory

National Marine Fisheries Service

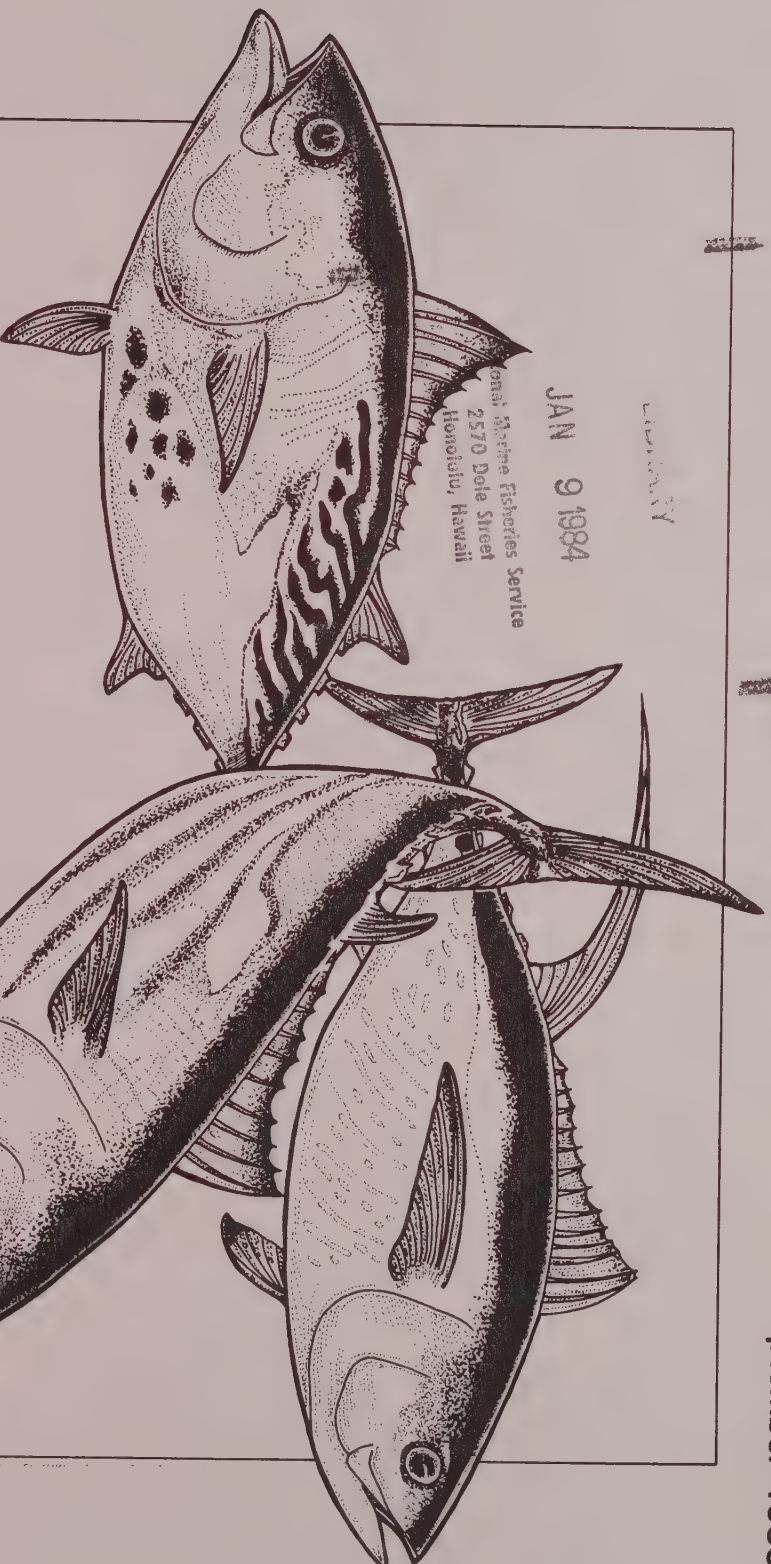
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FORWARD

Tuna stocks are distributed throughout the oceans of the world and form an important economic resource for many countries. In 1982, the estimated worldwide catch of all species of tuna was 2.5 million metric tons (2,205 pounds per metric ton) which was valued at \$2.8 billion. The United States alone processed 540 million pounds of canned tuna which was valued at \$885 million.

In the important commercial tuna fisheries of the world, prediction of the distribution and abundance of the various species of tunas that comprise the resource is a major biological problem. Analyses of environmental data from the Pacific over the years have provided correlations between tuna distribution and various oceanographic and meteorological variables, but the mechanisms determining the distribution, availability, and migrations of tunas

are not completely known. Temperature, oxygen, salinity, and food availability all influence tuna movements and limit their vertical and horizontal distributions. The Kewalo Research Facility of the Honolulu Laboratory is in the center of ongoing research programs designed to examine the effects of the most important environmental parameters on the behavior and physiology of tunas. These programs will ultimately allow fishermen and fisheries scientists to predict how environmental factors affect the distribution, availability, and movements of tunas.

The Honolulu Laboratory sees the role of the Kewalo Research Facility also as an international gathering place for scientists of varied backgrounds and disciplines. The uniqueness of this facility and past 25 years of quality research have engendered an enviable reputation for the Kewalo Research Facility throughout the world. During this period many respected scientists have taken the opportunity to study tunas under the controlled laboratory conditions available only at the Kewalo Research Facility.

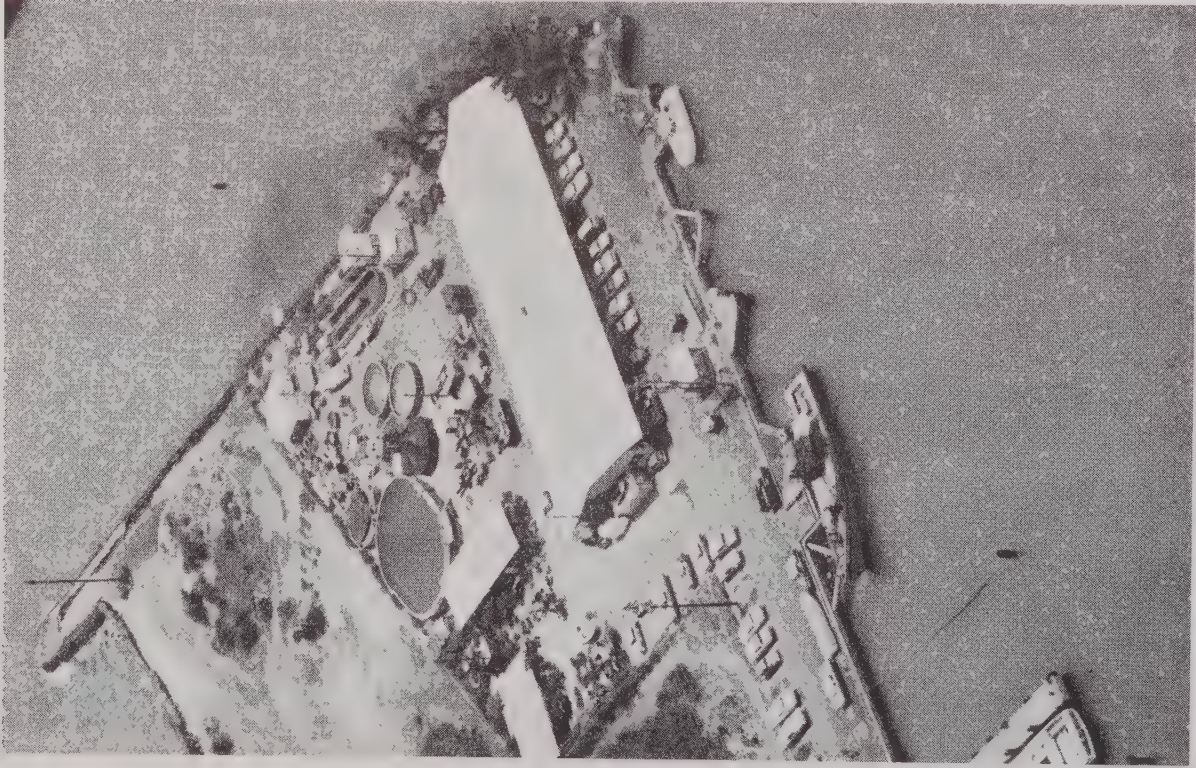
THE KEWALO RESEARCH FACILITY

"Kewalo" has been translated as "the place of wailing." Historical descriptions of the area on the Island of Oahu called Kewalo give meaning to the translation. In ancient times the section of the land called Kewalo contained a spring, which before the conversion to Christianity, was used as a place where human sacrifices, such as kauwa (outcasts), were first drowned before being taken to the Heiau of Kanelaa (temple) on the slopes of Punchbowl Crater for burning in the imu ahi (fire oven).

Kewalo Basin, as part of the modern city of Honolulu, is of course no longer used for such purposes. Today, Kewalo Basin is the home of many commercial and recreational fishing boats, a seafood cannery, a fresh fish auction house, and other marine related enterprises. Kewalo Basin is also the site of the Honolulu Laboratory's Kewalo Research Facility.

The site occupied by the Kewalo Research Facility was once a shallow, submerged coral reef. In 1945 the U.S. Navy dredged a small harbor in the coral reef to create Kewalo Basin, which was later turned over to the Territory of Hawaii. Subsequently, the harbor was enlarged and artificial and sanitary fill was used to create protecting land areas on the south and east sides of the harbor basin.

In July 1958, the Honolulu Laboratory of the National Marine Fisheries Service, then a part of the Fish and Wildlife Service, negotiated a lease to the grounds and building on the spit of artificially created land at the southeast entrance of Kewalo Basin to establish the Kewalo Research Facility. The facility has a low profile and goes unnoticed by many tourists, surfers, and fishermen that frequent the area. But within the 0.4 hectare (0.98 acre) area is a truly remarkable research facility. The main





Live tunas are presently collected by cooperating commercial pole-and-line fishermen. The fish are caught with barbless hooks and dropped into the vessel's bait holding tanks. When the vessel returns to Kewalo Basin, the fish are transferred into a waiting transfer tank with a chamolis-lined dip net. The transfer tank is then transported with a crane and lowered into a holding tank in which the fish freely swim. This handling technique, which has evolved over the years, minimizes injury to the fish.



building has over $1,003.4 \text{ m}^2$ ($10,800 \text{ ft}^2$) of space and houses offices, laboratories tailored for various research activities, a machine shop, and storage areas. A saltwater well on the adjoining grounds has the capacity to produce high quality coral filtered seawater at a rate of over 3,785 liters (1,000 gal) per minute. The filtered seawater is pumped to aerators to be oxygenated and then distributed to various tanks including a series of five 75,706-liter

(20,000-gal) circular pools, a 757,060-liter (200,000-gal) oceanarium, and specially designed experimental tanks of various sizes.

The Kewalo Research Facility is today, as it has been since its inception, the only research center in the world that is able to maintain live tunas in captivity throughout the year for use in behavioral and physiological research. Indeed, the Facility's international reputation continues to attract established scientists of diverse backgrounds and expertise to this unique laboratory where experiments requiring live tunas can be conducted.

RESEARCH ACTIVITIES

Early Work

Despite the worldwide distribution and high economic value of tuna stocks, very little research had been done with live specimens before 1958. The initial goals of the Kewalo Research Facility were to develop a program to maintain live tunas in captivity as experimental animals. Because there was little information available on live tunas, the early research was aimed at collecting data that would serve as the foundation for future investigations. This early work uncovered interesting facts about tunas.

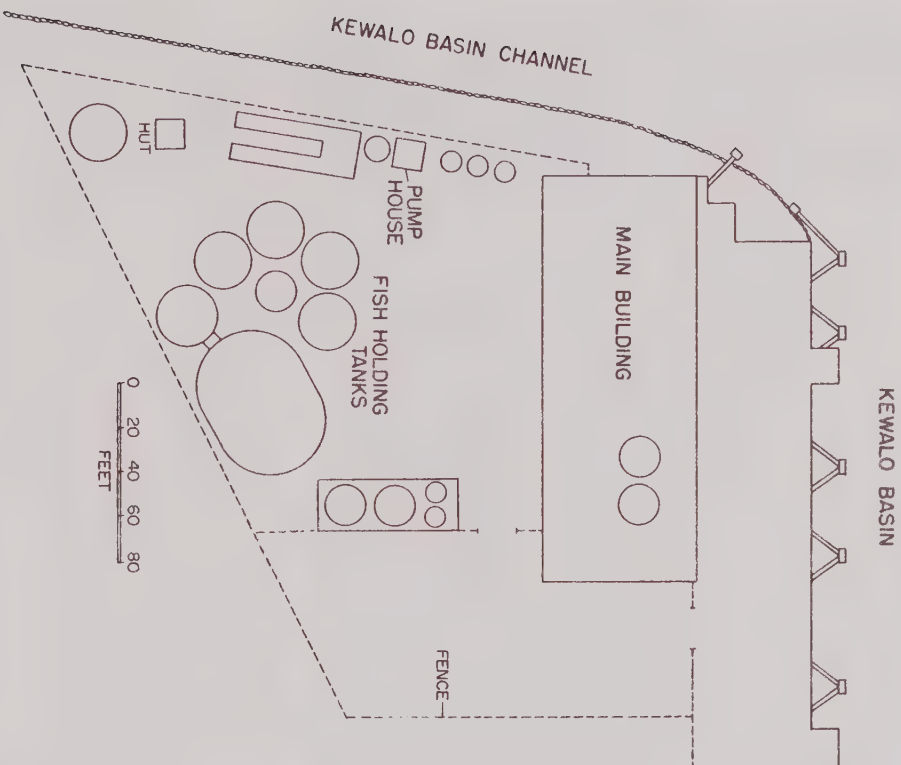
- Tunas are heavier than water and must continuously swim to keep from sinking. Tunas breathe by simply opening their mouths so that water is forced over their gills as they swim. Tunas sink and suffocate if they stop swimming.
- The basal swimming speed of tunas is dependent upon the lifting area of fins and the density of the fish, and is not a function of

either respiratory requirements or the search for food.

- All tunas have the following adaptations for continuous swimming: 1) a high hemoglobin level in the blood to carry sufficient oxygen to maintain continuous muscle activity; 2) a large proportion of the muscle made up of red muscle fibers that are specialized, like muscles of the heart, for continuous activity; and 3) a streamlined body shape to reduce hydrodynamic drag.
- In larger species of tunas, two morphological features evolved to reduce the energy required to keep from sinking. First, pectoral fins became larger to produce more lift; second, gas bladders developed to decrease density. Although gas bladders are very effective in reducing the density of fish, they limit the tuna's vertical movements. A fast vertical ascent to the surface can cause large changes in volume and, in the extreme, burst the gas bladder.

Other early experiments with the tunas were designed to determine their sensory abilities--how well they smell, taste, hear, see, and sense changes in water temperature. The rationale for these studies was that a basic understanding of the behavior and sensory capabilities of tunas would be useful in the future design of fishing gear and new fishing methods, and in locating tunas.

To determine how well tunas can see, studies were conducted on their visual acuity (the ability to see the fine details of objects). Of the three species tested, it was determined that yellowfin tuna, Thunnus albacares, could see better than skipjack tuna, Katsuwonus pelamis, and the latter better than kawakawa, Euthynnus affinis. Further experiments on

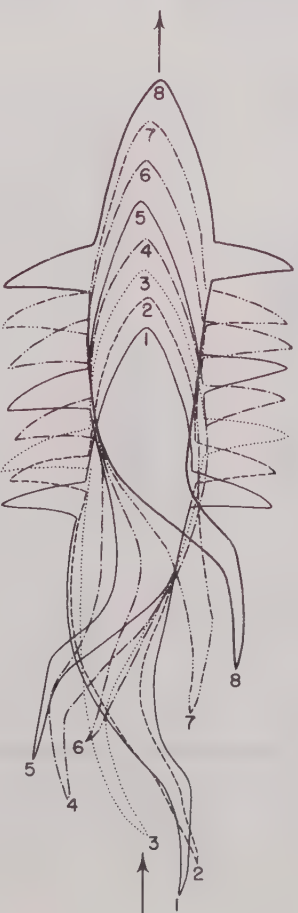


The Kewalo Research Facility is able to obtain and maintain tuna in captivity because of several conditions unique to its site. Commercial live bait tuna fishing boats dock literally at the laboratory's front door. Also, because the facility was built over a filled-in coral reef, and because of Hawaii's mild climate, the saltwater well is able to provide clean seawater at appropriate temperature for holding tunas the year round.

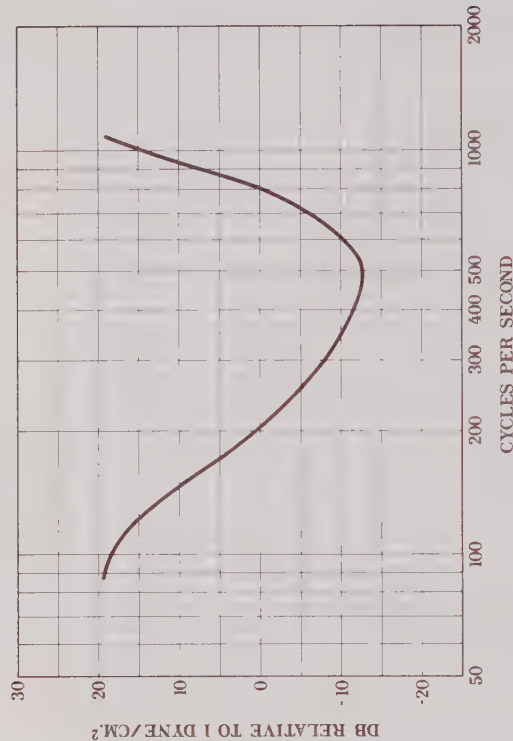
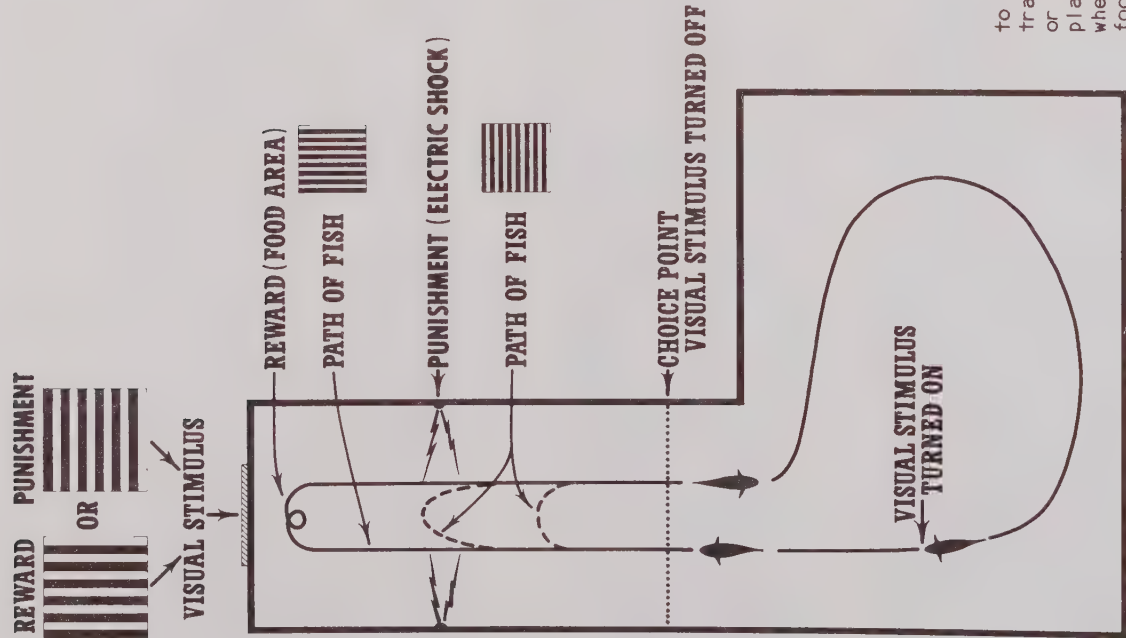
the optical system of restrained tuna showed that they are color-blind and are most sensitive to blue light.

Experiments to define the hearing ability of tunas made it possible to construct a hearing curve for a tuna, the first ever for a scombrid, and to determine their auditory thresholds (the lowest level of sound that can be heard at a specific frequency). It was determined that the hearing range of yellowfin tuna is from about 200 to 2,000 Hz, and that its hearing is most acute at 500 Hz.

Experiments at the Kewalo Research Facility also showed that tunas have a highly developed sense of smell. A strong response was elicited from a school of kawakawa when a liter (1.06 qt) of water in which a

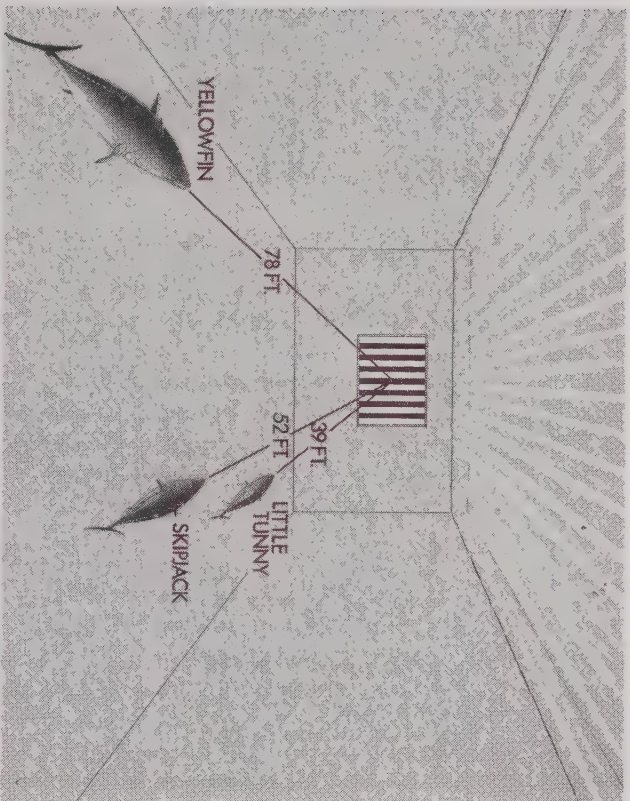


The facilities at Kewalo made it possible to closely observe captive fish and produced the first high-speed movies of swimming kawakawa. The analysis of the film provided intimate details of swimming speed, tail beat rates, body postures and flexures, and how the changing positions of fins and finlets provide drag reduction features. It was determined that the tail provided nearly 100% of the forward thrust and that the fish attained burst speeds of twice that of nonscombrid fish. The line drawing shown here was traced from successive cine frames (camera speed 100 frames per second) for one complete caudal fin beat cycle of a kawakawa. The swimming speed of this fish was 8.2 body lengths per second which was produced by a tail beat frequency of 14.3 tail beats per second.



Experiments to determine the hearing ability of tunas were conducted in a pool specially constructed to insulate the fish from outside sounds and electronic interference. The test fish were first trained to recognize a pure "white" sound and then to react to the sound stimulus by swimming through a maze for a reward. The yellowfin tuna best hears sounds that are near 500 Hz as shown by the dip at that frequency in the hearing curve. Sounds near this frequency are common in the ocean, as for example, the sound produced by the swimming of a school of small fish.

This diagram illustrates the experimental method used to determine the visual acuity of tunas. The method involves training a fish to respond to a visual stimulus (horizontal or vertical stripes), projected on an opal glass plate placed against a tank window. The fish is trained so that when the stripes are vertical it swims down the tank to a food-drop area where it is rewarded; when the stripes are horizontal the fish is trained to turn before it reaches the food-drop area and return to the far end of the tank. If the fish fails to turn it receives an electrical shock.



To measure tuna's reaction to various sensory stimuli, an observer must be able to detect the fish's response to these stimuli. It was found that tunas can be trained to perform a specific act in response to stimuli if they were rewarded. To measure how well they can see, tunas were trained to respond differently to vertical and horizontal bars that were projected onto an underwater screen by giving rewards (food) or punishment (electric shock). These experiments showed that at a constant brightness, a yellowfin tuna sees details of an object better than a skipjack tuna and a skipjack tuna better than a kawakawa.

small fish (a smelt weighing 10 g or 0.4 oz) had been dipped for 10 seconds was introduced to their holding tank. It should be noted that the response was elicited even though the rinse water was further diluted by its introduction through the inflow seawater system. A study of the morphological structure of the nares (nose) of the tunas revealed that they can "sniff" the water. Each jaw movement of

a tuna produces a pumping action that forces water past their nasal rosettes (odor receptors). Observations of fish in captivity showed this pumping action to be continuous.

Two other research projects were designed to determine tunas' ability to perceive changes in water temperature. One experiment made use of the observation that the heart rate of a restrained tuna slows when the fish is presented with an external stimulus, such as a change in water temperature. In the second experiment a free swimming fish was rewarded with food each time it was able to recognize a temperature difference when cooler or warmer water was added to the tank. In restrained fish, a temperature change of 1°C elicited a response. Free swimming fish were able to perceive a temperature difference of as little as 0.1°C .

Other early work in the feeding and digestion rates of tunas showed that these fish can digest a meal several times faster than other fish species. Prey organisms are not homogeneously distributed in the open ocean, but are found in patchy concentrations in space and time. Tunas, thus, exist in a "feast or famine" situation and must eat whenever they find food. Knowledge of digestion and feeding rates of fishes adapted to such environments is important for the understanding of growth and the worldwide distribution of tunas and can be of practical value to commercial fishermen.

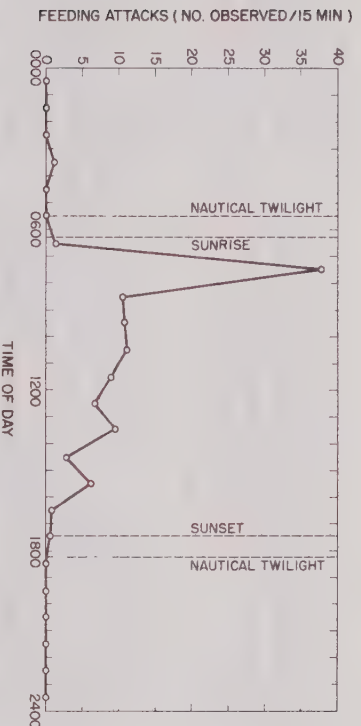
As techniques for capture, transport, and maintenance of tunas improved, the number of live tunas available for experimental purposes increased proportionately. This has made it possible to increase the variety of behavioral and physiological studies conducted at the Kewalo Research Facility.



In this photograph a kawakawa is making an aggressive move towards a school of nehu in a shoreside research tank. Kawakawa has proved to be a good laboratory research animal and is readily available in Hawaiian waters.



Upon swimming into an odor cloud of prey or other food items, tunas will typically increase their swimming speed, break the school swimming formation, and display the various color patterns associated with feeding. Kawakawa (pictured) display ventral spots and dorsal stripes; skipjack tuna exhibit lateral vertical bars and a dorsal white stripe and yellowfin tuna show the same color pattern as skipjack tuna plus a dark dorsal coloration.



The changes in the feeding activity of kawakawa during a 24-hour period as shown in this graph is typical for all tunas. When tunas in captivity were provided with a constant supply of food, feeding motivation was highest at early morning followed by a rapid decrease through noon and two smaller peaks at midafternoon. They showed no attempts to feed at night. This behavior is consistent with the high consumption and digestion of tunas which is from two to five times faster than that of other fish. When tunas are fed continuously, an equivalent of 15% of body weight or two times their stomach volume is eaten. The drive to attack prey is dependent on the amount of food in the stomach. Intense feeding always occurs in the morning when the stomach is empty. However, the stomach is not filled to capacity at the first feeding frenzy and the fish feeds throughout the day. Feeding slows when the stomach is 80% filled.

Later Work

More recent work at the Kewalo Research Facility has included efforts to develop a mathematical model of the energy requirements of skipjack tuna. Such a model enables scientists to better explain and predict the abundance and maximum sustainable yields of all species of tunas. Much of the data collected over the past quarter century have been used in this model. Results indicate that the growth rate of skipjack tuna less than 11.8 kg (26 lb) is governed by food consumption, whereas the growth rate of fish larger

than 15.0 kg (33 lb) is limited by the energetic demands of activity. Other work, using data from laboratory experiments on tuna combined with oceanographic information, indicated that the distribution of small fish is dependent on the availability of food whereas the distribution of large fish is dependent on environmental conditions, of which temperature and oxygen levels play major roles.

Additional studies at the Kewalo Research Facility confirmed that tunas have a remarkable ability to maintain body temperatures higher than the temperature of the water in which they swim. This ability is attributable to vascular countercurrent heat exchangers that retain the heat produced by metabolic activity within the muscles. In other bony fishes metabolic heat is lost into the surrounding water via the gills and body surface.

As a predator, the ability to maintain an elevated body temperature probably gives tunas an advantage over other fishes because it allows the tuna to operate at higher activity levels. Depending on the activity and size of the fish, muscle temperature can range from 2° to 21°C above ambient water temperature.

The accumulation of knowledge on the effects of temperature on the tuna physiology allowed work on more sophisticated experiments, such as those designed to determine whether tunas can physiologically or behaviorally thermoregulate. The first evidence of physiological thermoregulation in tunas was obtained in experiments with yellowfin tuna. Yellowfin tuna placed in a doughnut-shaped tank were able to alter their body temperature independently of swimming speed (that is physiologically thermoregulate) as the water temperature was changed at 12-hour intervals. This ability to physiologically thermoregulate, however, has not yet been demonstrated in all species of tuna.

Current Work

Tuna Bioenergetics

Tuna metabolic rates present an interesting paradox. Tunas are more energetic than other fishes yet they inhabit a very food-poor environment: the tropical oceans. How do tunas obtain the energy for so much activity when they live in a virtual desert? Anyone seeing the sleek, streamlined shape of a swimming tuna is impressed with its design for speed. Each of five swimming fins can be withdrawn into a slot or recess, leaving the body surface perfectly smooth. Despite their hydrodynamically designed bodies, tunas require more energy to swim at their cruising speed than do other fishes when forced to swim at the same speeds. Shouldn't tunas be more efficient? The measurement of tuna metabolic rates has a long history at the Kewalo Research Facility. Past projects included measurement of standard metabolic rate (metabolic rate at zero activity), and studies of the effects of size, temperature, and speed on active metabolic rate.

Current work is designed to reexamine earlier results based on oxygen consumption (respirometry), by directly measuring changes in whole fish energy content (calorimetry). To determine the relationship between speed and energy consumption, wild skipjack tuna, kawakawa, and yellowfin tuna are being compared with experimentally manipulated fish caught from the same schools.

Answers to the paradox of high metabolic rates may come from the advantages a high metabolic rate provides with respect to agility and mobility in hunting and capturing prey. The data indicate that tunas become more efficient than other fishes at higher swimming speeds. For tunas, high metabolic rates at low activities may be a physiological

necessity for greater efficiency at high swimming speeds during feeding or when escaping from predators. The unique ability of tunas to conserve metabolic heat may also turn high metabolic rates to advantage by keeping the tuna's swimming muscles warm when they penetrate cold, deep water in pursuit of prey.

Investigators are working at the Kewalo Research Facility to determine the characteristics of muscle physiology needed to link data on tuna bioenergetics with mathematical hydrodynamic models of power output. Aside from providing basic insight into the physics of swimming, these models, derived in cooperation with researchers from the University of Wisconsin and California Institute of Technology, should provide a useful tool for predicting energy consumption at the population level. Such predictions will, in turn, permit better estimates of tuna abundance and productivity for eventual applications to fishery management.

Olfaction

Work conducted 20 years ago at the Kewalo Research Facility established that tunas have an excellent sense of smell that is capable of detecting the very dilute odor of their prey. Recent research with captive and wild tuna indicates that they can distinguish between odors of different types of prey, and that some prey odors cause stronger search behavior than others. These data indicate that tuna probably use their sense of smell to detect prey before they come within visual range.

Current research is aimed at analyzing the chemical structure of the prey odors and testing various synthetic prey odors for eliciting a feeding response. Eventually, it may be possible to use these natural and synthetic odors to enhance the effectiveness of traditional fishing techniques. If

an inexpensive synthetic odor can be formulated, it could be used in the live-bait and the handline tuna fisheries to increase catch success and decrease the dependency on expensive natural bait.

Spawning

The first successful attempts to artificially induce spawning in captive tuna were accomplished at the Kewalo Research Facility. The technique involved a periodic biopsy of kawakawa to determine the developmental stage of the eggs in the ovaries. After the eggs attained a critical size, hormone treatments were administered to the fish to induce spawning. Today, because of recent advances in techniques and knowledge, hormone treatments are no longer used and (during the summer months) skipjack tuna routinely spawn in our shoreside facilities shortly after arrival. This has enabled researchers to investigate the techniques needed to rear larval pelagic fish.

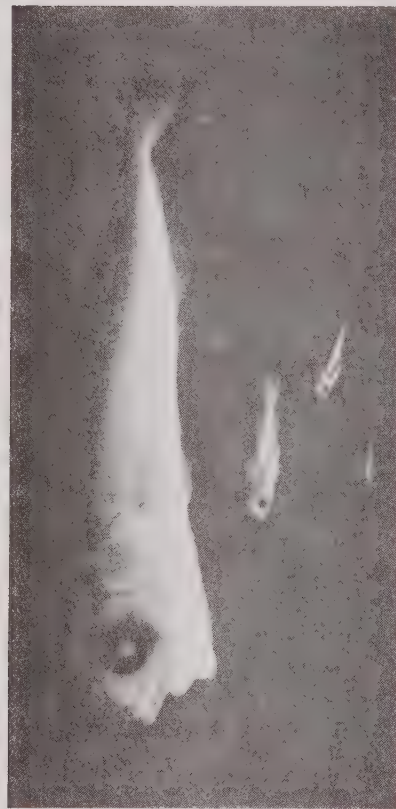
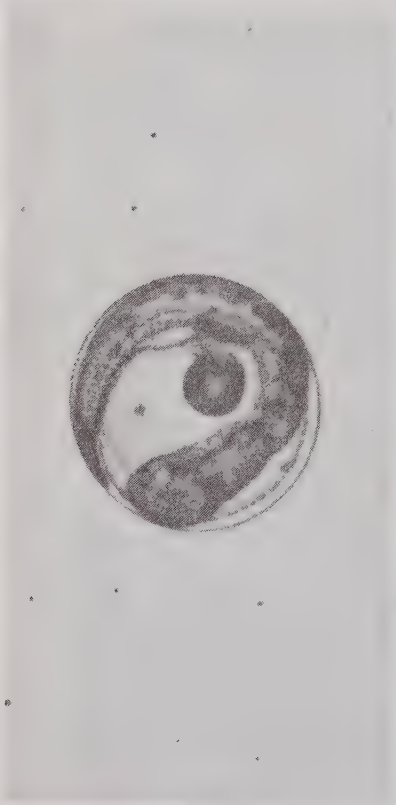
Tuna eggs hatch about 24 hours after fertilization and the yolk sacs of the larvae are absorbed in about 2 days. At this critical stage, the larval tuna must forage for food. To meet the nutritional requirements of larval tuna, the Kewalo Research Facility maintains a culture system for species of phytoplankton, rotifers, and copepods. These foods are of different sizes and nutritional values and must be present at each critical stage of the tuna's development. The technology developed to rear larval tuna is opening new fields of research that will focus on the previously unobservable day-to-day development and early life history of pelagic fish. Currently, larval tuna are the subjects of studies designed to determine their growth, development, behavior, neuroanatomy, energetics, and development of geomagnetic sensitivity.

Geomagnetic Sensitivity

Tunas are among the most highly migratory fishes. An understanding of migration is central to an understanding of the distribution of tuna stocks. Migration represents a substantial investment of energy for migrating fish, and it might be expected that there has been intense evolutionary pressure on the sensory systems responsible for guiding migration. However, no special abilities useful in navigation have been detected among the commonly recognized sense systems (vision, smell, taste, etc.) of tunas. One exciting possibility is that tunas possess a magnetic compass sense capable of guiding their migrations.

Studies are currently underway to test the ability of yellowfin tuna to discriminate between different magnetic fields. The fish are pretrained to perform a conditioned response (swimming through a hoop) at a consistent rate. The fish are then tested by rewarding them with food when one magnetic field is present in the tank and by punishing them (by withholding food) when the second field is present. If the fish are able to detect the difference between the two magnetic fields, maintaining a high rate of response during positively reinforced trials will maximize food rewards, whereas a low rate of response during negatively reinforced trials will minimize the cost of responding. Thus, discrimination is measured as a difference in the rates at which the fish swim through the hoop in anticipation of positive or negative reinforcement.

Results show that yellowfin tuna can learn to use magnetic field information to make appropriate decisions about their experimental situation. The first conclusion from these studies is that yellowfin tuna possess a magnetic sense which probably could be

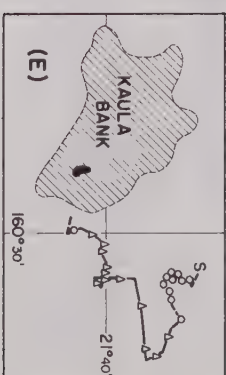
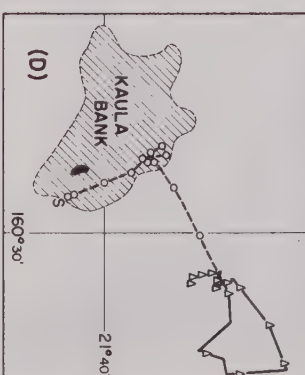
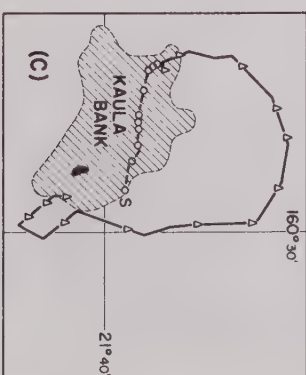
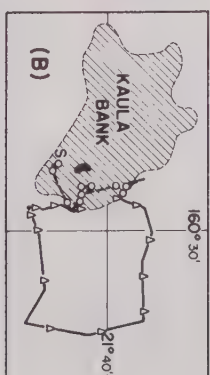
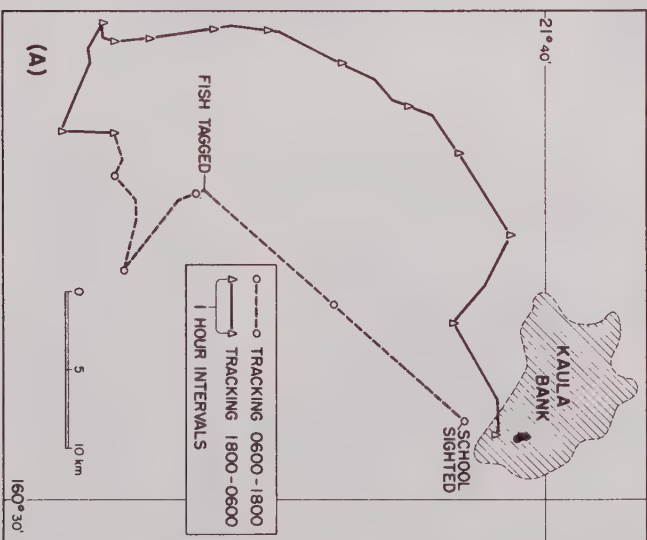
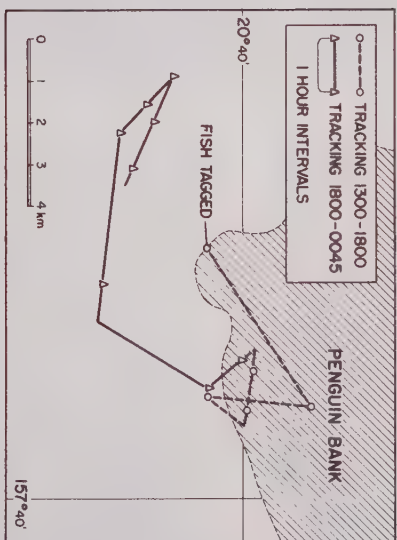


used for navigation. Continuing studies are testing for magnetic sensitivity in kawakawa and skipjack tuna.

Related studies are aimed at determining whether the fish use crystals of magnetite (lodestone) as the basis for their magnetic sense. A yellowfin tuna has been shown to contain up to 10 million crystals of magnetite. The fish produce the magnetite under very closely controlled conditions of size, shape, and chemical composition in a tissue within the ethmoid bones of the skull. A large branch of the anterior lateral line nerve ramifies in the area of the ethmoid bones of tunas. It is therefore possible that a



The different stages of development of skipjack tuna spawned at the Kewalo Research Facility are shown in this series of pictures. The first picture is of an egg that has been nurtured in the laboratory for about 16 hours since fertilization. The second picture catches a larvae just hatching, about 21 hours after fertilization. The third picture is of a larvae less than 24 hours old. The large yolk sac will be absorbed about 48 hours after hatching, and the fish must then actively forage for food. The fourth picture shows the rapid growth in the early life of a skipjack tuna. The ages from the largest to the smallest are 35, 20, 18, and 3 days old.



The Honolulu Laboratory was one of the pioneers in the use of sonic tags to track tuna in the open ocean.

These figures show the tracks of skipjack tuna tagged with sonic tags near Penguin Bank and Kaula Bank. (Track of tagged skipjack tuna at Kaula Bank: (A) from 1452, August 30, to 0600, August 31; (B) from 0600, August 31, to 0600, September 1; (C) from 0739, September 3, to 0600, September 4; (D) from 0600, September 4, to 0600, September 5; (E) from 0600, September 5, to 0730, September 6.)

These results confirmed for the first time that skipjack tuna are temporarily territorial and remain in a given area for some time in Hawaiian waters. Also of interest is the fish's repeated returns to the same area each morning, which implies that skipjack tuna can navigate and have a sense of time.

branch of this nerve may be associated with the magnetite crystals, forming a magnetoreceptor organ. Work is continuing on the structure and anatomy of the magnetite-bearing tissue contained in the ethmoid bones.

Physiological Laboratory

The Kewalo Research Facility has a laboratory specifically designed for neurophysiological, cardiovascular, and general physiological experiments on tunas. The laboratory contains a vibration-free operating table with running seawater. Tuna can be effectively restrained on the table in a padded Plexiglas¹ trough or box and often will survive in excess of 8 hours in this situation.

The laboratory is currently being used to investigate the neurophysiological responses of tunas to odors and to changes in the Earth's magnetic field. A series of experiments to measure the rate of oxygen uptake of quiescent fish (the so-called "standard metabolic rate") is also in progress. The physiological studies on restrained tuna are specifically designed to complement the data obtained from free swimming fish's responses to various odor and magnetic stimuli and measurements of the metabolic rate.

BASE FOR RESEARCH VESSEL

The Kewalo Research Facility has also served as the base for research vessels operated by the Honolulu Laboratory. At various times, the research vessels Hugh M. Smith, Charles H. Gilbert, and Townsend Cromwell have docked at the shoreside facility. The

¹Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.



The RV Kaahale'ale is pictured leaving on a dual mission to confirm results of experiments conducted at the Kewalo Research Facility. In addition to the normal fishing, navigational, and oceanographic equipment on board, a hydrophone is mounted at the bottom of the vertical pole located amidship. After a tuna is successfully tagged with an ultrasonic transmitter and released, the receiver is lowered into the water and the horizontal and vertical movements of the fish are then recorded. On the stern of the vessel is secured a shark cage from which divers will observe the behavioral reactions of fish to natural and synthetic prey odors.

Townsend Cromwell is now docked at Snug Harbor (part of Honolulu Harbor); but, the Kewalo Research Facility still serves as a base of operation for research cruises.

The Kewalo Research Facility now has at its disposal the RV Kaahale'ale. This 33-ft vessel is capable of returning live specimens to the laboratory and is equipped with sophisticated electronics and navigational equipment to track the vertical and horizontal movements of tunas and billfishes carrying

ultrasonic transmitters. The vessel is an integral part of the Facility and is in constant demand to test the results of theoretical and experimental investigations conducted at the Kewalo Research Facility.



The research activities of the Honolulu Laboratory cover a wide reach of the tropical and subtropical Pacific Ocean. From 1950 to the present, research vessels of the Honolulu Laboratory sailed over 1 million nautical miles on oceanographic and fishery cruises. Currently, the 48.2 m (158-ft) NOAA vessel Townsend Cromwell is under assignment to the Honolulu Laboratory for its use. In the past the Honolulu Laboratory operated the Henry O'Malley, John R. Manning, Hugh M. Smith, and the Charles H. Gilbert.

RELATIONSHIP WITH UNIVERSITY OF HAWAII

The Honolulu Laboratory (through its Kewalo Research Facility and in other ways) maintains a special relationship with the University of Hawaii. There is free dialogue and exchange of information among scientists in the University's Departments of Zoology, Physiology, Oceanography, Biochemistry, Nutrition, and Animal Sciences and researchers working at the Kewalo Research Facility. The Honolulu Laboratory has provided part-time employment for University of Hawaii undergraduates and support for master's and doctoral degree candidates by providing laboratory space, experimental tuna, and monetary grants. Laboratory scientists have also served as advisors on graduate student thesis committees. These activities have provided enrichment to the mutual benefit of the University of Hawaii and the Kewalo Research Facility.

Graduate students from the University of Hawaii (and other universities) who have earned advanced degrees that included research work at the Kewalo Research Facility have included:

Andrew Ayers	Department of Zoology University of Hawaii	Robert Bourke	Department of Animal Sciences University of Hawaii
C. Scott Baker	Department of Zoology University of Hawaii	Richard W. Brill	Department of Physiology University of Hawaii
Michael Barry	Department of Zoology University of Hawaii	Michael Guppy	Department of Zoology University of British Columbia
Gordon Bauer	Department of Psychology University of Hawaii	Sharon D. Hendrix	Department of Zoology University of Hawaii
Christopher Boggs	Laboratory of Limnology University of Wisconsin	Walter N. Ikehara	Department of Zoology University of Hawaii
		Barbara A. Kuljis	Kewalo Basin Marine Animal Facility University of Hawaii
		Elizabeth A. Monckton	Department of Zoology University of Hawaii
		Robert Olson	Department of Biology San Diego State University
		Linda M. B. Paul	Department of Zoology University of Hawaii
		Anjanette S. Perry	Department of Oceanography University of Hawaii
		John Salamonski	Department of Physiology and Pharmacology University of St. Andrews St. Andrews, Scotland
		Sherry Steffel	Laboratory of Limnology University of Wisconsin

Anthony Sudekum	Department of Zoology University of Hawaii	Dr. Grant R. Bartlett	Laboratory of Comparative Biochemistry San Diego, California
Michael M. Walker	Department of Zoology University of Hawaii	Dr. William P. Braker	John G. Shedd Aquarium Chicago, Illinois
Minato Yasui	Shizuoka Prefectural Fisheries Experimental Station Shizuoka, Japan	Dr. Phyllis H. Cahn	Department of Biology C. W. Post Center Long Island University Grenvale, New York

LIST OF VISITING INVESTIGATORS

The Kewalo Research Facility has hosted visiting scientists since its inception because it is the only laboratory in the world that routinely maintains live tunas specifically for behavioral and physiological research. (An operations and procedures manual for prospective visiting scientists at the Kewalo Research Facility is available as Southwest Fisheries Center Administrative Report H-83-7.) Visiting scientists of diverse backgrounds have come from around the world to work at the Kewalo Research Facility and have included:

Dr. Jelle Atema	Marine Biological Laboratory Boston University Woods Hole, Massachusetts	Dr. Christopher French	Department of Zoology University of British Columbia Vancouver, B.C., Canada
Dr. John E. Bardach	Resources Systems Institute East-West Center Honolulu, Hawaii	Dr. F. E. J. Fry	Department of Zoology University of Toronto Toronto, Ont., Canada

Dr. Francis G. Carey
Woods Hole Oceanographic
Institution
Woods Hole, Massachusetts

Dr. Jean L. Cramer
Department of Animal
Sciences
University of Hawaii
Honolulu, Hawaii

Dr. Charles Daxboeck
Pacific Gamefish
Foundation
Kailua-Kona, Hawaii

Dr. Brian Emmett
Department of Zoology
University of British
Columbia
Vancouver, B.C., Canada

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| Dr. F. W. Goetz, Jr. | Department of Biology
University of Notre Dame
Notre Dame, Indiana | Dr. Kim Holland | Hawaii Institute of
Marine Biology
University of Hawaii
Kaneohe, Hawaii |
| Dr. Malcolm S. Gordon | Department of Biology
University of California
Los Angeles, California | Dr. C. S. S. Holling | Institute of Animal
Resource Ecology
University of British
Columbia
Vancouver, B.C., Canada |
| Dr. E. Gordon Grau | Department of Zoology
University of Hawaii
Honolulu, Hawaii | Dr. William C. Hulbert | Department of Zoology
University of British
Columbia
Vancouver, B.C., Canada |
| Dr. Isao Hanyu | Laboratory of Fish
Physiology
University of Tokyo
Tokyo, Japan | Dr. Ian Johnston | Department of Physiology
and Pharmacology
University of St. Andrews
St. Andrews, Scotland |
| Dr. Teruo Harada | Fisheries Laboratory
Kinki University
Wakayama, Japan | Dr. John W. Kanwisher | Woods Hole Oceanographic
Institution
Woods Hole, Massachusetts |
| Dr. Alan R. Hargens | Department of Surgery
Veterans Administration
Hospital
University of San Diego
San Diego, California | Dr. Sergey M. Kashin | Institute of Oceanology
Academy of Sciences
Moscow, U.S.S.R. |
| Dr. F. Havard-Duclois | Centre National pour
l'Exploitation des
Océans
Brest, France | Dr. Calvin M. Kaya | Department of Zoology
Montana State University
Bozeman, Montana |
| Dr. Peter W. Hochachka | Department of Zoology
University of British
Columbia
Vancouver, B.C., Canada | Dr. Robert E. Kearney | South Pacific Commission
Noumea, New Caledonia |
| | | Dr. James F. Kitchell | Department of Limnology
University of Wisconsin
Madison, Wisconsin |

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|------------------------|--|------------------------|---|
| Dr. John J. Magnuson | Department of Limnology
University of Wisconsin
Madison, Wisconsin | Dr. Arthur J. Niimi | Canada Centre for Inland
Waters
Burlington, Ont., Canada |
| Michael A. McCoy | Micronesia Maritime
Authority
Kolonia, Ponape
Eastern Caroline Islands | Dr. Hiroshi Niwa | Department of Fisheries
Nagoya University
Nagoya, Japan |
| Dr. John M. Miller | Department of Zoology
University of North
Carolina
Raleigh, North Carolina | Dr. Elmer R. Noble | Department of Biological
Sciences
University of California
Santa Barbara, California |
| Dr. Shigeru Miyashita | Fisheries Laboratory
Kinki University
Wakayama, Japan | Dr. Kenneth R. Olson | South Bend Center for
Medical Education
Indiana University School
of Medicine
Notre Dame, Indiana |
| Dr. Thomas W. Moon | Huntsman Marine Laboratory
Brandy Cove
St. Andrews, N.B., Canada | Dr. Steve Perry | Department of Biology
McMaster University
Toronto, Ont., Canada |
| Dr. Barry S. Muir | Marine Ecology Laboratory
Bedford Institute of
Oceanography
Dartmouth, N.S., Canada | Dr. Douglas G. Pincock | Department of Electrical
Engineering
University of New
Brunswick
Fredericton, N.B., Canada |
| Dr. A. Earl Murchison | Naval Undersea Center
Kailua, Hawaii | Dr. Warren P. Porter | Laboratory of Limnology
University of Wisconsin
Madison, Wisconsin |
| Dr. Claude M. Nagamine | Institute of Marine
Resources
University of California
Davis, California | Dr. John H. Prescott | Oceanarium, Inc.
Palos Verdes Estates,
California |
| Dr. William H. Neill | Department of Wildlife and
Fisheries Sciences
Texas A&M University
College Station, Texas | | |

Dr. Martin D. Rayner	Pacific Biomedical Research Center University of Hawaii Honolulu, Hawaii	Dr. E. E. Suckling	Downstate Medical Center State University of New York Brooklyn, New York
Dr. Terence A. Rogers	John A. Burns School of Medicine University of Hawaii Honolulu, Hawaii	Dr. J. A. Suckling	Department of Zoology Hunter College of the City University of New York New York, New York
Dr. Bryant T. Sather	Department of Zoology and Physiology Rutgers University Newark, New Jersey	Dr. Tamotsu Tamura	Agriculture Fisheries Laboratory Nagoya University Nagoya, Japan
Dr. Edward D. Scura	Aquatic Farms Kahaluu, Hawaii	Dr. Vladimir Walters	Department of Zoology University of California Los Angeles, California
Dr. Gary D. Sharp	Inter-American Tropical Tuna Commission La Jolla, California	Dr. Daniel Weihs	Department of Aeronautical Engineering Technion-Israel Institute of Technology Haifa, Israel
Dr. E. Don Stevens	Department of Zoology University of Guelph Guelph, Ont., Canada		

PARTIAL LIST OF SCIENTIFIC PUBLICATIONS RESULTING FROM RESEARCH AT THE KEWALO RESEARCH FACILITY

Tester, A. L.

1959. Summary of experiments on the response of tuna to stimuli. In H. Kristjansson (editor), Modern fishing gear of the world, p. 538-542. Fish. News (Books) Ltd., Lond.

Nakamura, E. L.

1960. Confinement of skipjack in a pond. (Abstr.) Proc. Hawaiian Acad. Sci., 35 Annu. Meet. 1959-1960, p. 24-25.
1962. Observations on the behavior of skipjack tuna, Euthynnus pelamis, in captivity. Copeia 1962:499-505.

Gooding, R. M.

1963. The olfactory organ of the skipjack Katsuwonus pelamis. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, Calif., 2-14 July 1962. FAO Fish. Rep. 6, 3:1621-1631.

Magnuson, J. J.

1963. Tuna behavior and physiology, a review. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, Calif., 2-14 July 1962. FAO Fish. Rep. 6, 3:1057-1066.

1964. Activity patterns of scombrids. (Abstr.) Proc. Hawaiian Acad. Sci., 39 Annu. Meet., 1963-1964, p. 26.

1964. Tuna behaviour programme at Honolulu.

- In Modern fishing gear of the world 2:560-562. Fish. News (Books) Ltd., Lond.

Nakamura, E. L.

1964. A method of measuring visual acuity of scombrids. (Abstr.) Proc. Hawaiian Acad. Sci., 39 Annu. Meet., 1963-1964, p. 26-27.

1964. Salt well water facilities at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu. In J. R. Clark and R. L. Clark (editors), A collection of papers on sea-water systems for experimental aquaria. U.S. Fish Wildl. Serv., Res. Rep. 63:169-172.

Magnuson, J. J.

1965. Tank facilities for tuna behavior studies. Prog. Fish-Cult. 27:230-233.

Manar, T. A.

1965. Tuna behavior. A growing field for research. Pac. Fisherm. 63(11):9-11.

Nakamura, E. L., and J. J. Magnuson.

1965. Coloration of the scombrid fish Euthynnus affinis (Cantor). Copeia 1965: 234-235.

Suckling, E. E.

1965. Mode of action of the lateral line organ receptors in fish. (Abstr.) Physiol-ogist 8:283.

- Iversen, R. T. B.
1966. Hearing in tunas with special reference to Euthynnus yaito Kishinouye. (Abstr.) Abstracts of Papers Related With Fisheries, Marine and Freshwater Science. Divisional Meeting on Fisheries Sciences, p. 25. Proc. 11 Pac. Sci. Congr., Tokyo, 1966, vol. 7.
- Magnuson, J. J.
1966. A comparative study of the function of continuous swimming by scombrid fishes. (Abstr.) Abstracts of Papers Related With Fisheries, Marine and Freshwater Science. Symposium on Biological Studies of Tunas and Sharks in the Pacific Ocean, p. 15. Proc. 11 Pac. Sci. Congr., Tokyo, 1966, vol. 7.
1966. Continuous locomotion in scombrid fishes. (Abstr.) Am. Zool. 6:503-504.
- Murchison, A. E., and J. J. Magnuson.
1966. Notes on the coloration and behavior of the common dolphin, Coryphaena hippurus. Pac. Sci. 20:515-517.
- Nakamura, E. L.
1966. Fiberglass tanks for transferring of pelagic fishes. Prog. Fish-Cult. 28:60-62.
- Walters, V.
1966. On the dynamics of filter-feeding by the wavyback skipjack (Euthynnus affinis). Bull. Mar. Sci. 16:209-221.
- Cahn, P. H.
1967. Some observations on schooling of tunas (motion picture). (Abstr.) Am. Zool. 7:199.
- Iversen, R. T. B.
1967. Response of yellowfin tuna (Thunnus albacares) to underwater sound. In W. N. Tavolga (editor), Marine bio-acoustics 2:105-119, discussion, p. 119-121. Proceedings of the Second Symposium on Marine Bio-Acoustics held at the American Museum of Natural History, New York, April 13-15, 1966. Pergamon Press, Oxford and N.Y.
- Marr, J. C.
1967. Research programme of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Proceedings of the Symposium on Scombroid Fishes, Part 3, p. 1154-1157. Mar. Biol. Assoc. India. Symp. Ser. 1.
- Rayner, M. D., and M. J. Keenan.
1967. Role of red and white muscles in the swimming of the skipjack tuna. Nature (Lond.) 214:392-393.
- Sather, B. T., and T. A. Rogers.
1967. Some inorganic constituents of the muscles and blood of the oceanic skipjack, Katsuwonus pelamis. Pac. Sci. 21:404-413.
- Suckling, E. E.
1967. Electrophysiological studies on the trunk lateral line system of various marine and freshwater teleosts. In P. H. Cahn (editor), Lateral line detectors, p. 97-103. Indiana Univ. Press, Bloomington.
- Suckling, J. A.
1967. Trunk lateral line nerves: Some anatomical aspects. In P. H. Cahn (editor), Lateral line detectors, p. 45-52. Indiana Univ. Press, Bloomington.

- Chang, R. K. C., and J. J. Magnuson.
1968. A radiographic method for determining gas bladder volume of fish. *Copeia* 1968: 187-189.
- Fierstine, H. L., and V. Walters.
1968. Studies in locomotion and anatomy of scombrid fishes. Mem. South. Calif. Acad. Sci. 6:1-31.
- Gordon, M. S.
1968. Oxygen consumption of red and white mus-
cles from tuna fishes. Science (Wash.,
D.C.) 159:87-90.
- Nakamura, E. I.
1968. Visual acuity of two tunas, Katsuwonus
pelamis and Euthynnus affinis. *Copeia*
1968:41-49.
- Iversen, R. T. B.
1969. Auditory thresholds of the scombrid fish
Euthynnus affinis, with comments on the use
of sound in tuna fishing. In A. Ben-Tuvia
and W. Dickson (editors), Proceedings of the
FAO Conference on Fish Behaviour in Relation
to Fishing Techniques and Tactics, Bergen,
Norway, 19-27 October 1967. FAO Fish. Rep.
62, 3:849-859.
- Magnuson, J. J.
1969. Digestion and food consumption by skip-
jack tuna (Katsuwonus pelamis). Trans. Am.
Fish. Soc. 98:379-392.
1969. Swimming activity of the scombrid fish
Euthynnus affinis as related to search for
food. In A. Ben-Tuvia and W. Dickson (edi-
tors), Proceedings of the FAO Conference on
Fish Behaviour in Relation to Fishing Tech-
niques and Tactics, Bergen, Norway, 19-27
October 1967. FAO Fish. Rep. 62, 2:439-451.
- Nakamura, E. I.
1969. A review of field observations on tuna
behavior. In A. Ben-Tuvia and W. Dickson
(editors), Proceedings of the FAO Conference
on Fish Behaviour in Relation to Fishing
Techniques and Tactics, Bergen, Norway, 19-
27 October 1967. FAO Fish. Rep. 62, 2:59-
68.
1969. Visual acuity of yellowfin tuna, Thun-
nus albacares. In A. Ben-Tuvia and W. Dick-
son (editors), Proceedings of the FAO Con-
ference on Fish Behaviour in Relation to
Fishing Techniques and Tactics, Bergen,
Norway, 19-27 October 1967. FAO Fish. Rep.
62, 3:463-468.
- Brown, C. E., and B. S. Muir.
1970. Analysis of ram ventilation of fish
gills with application to skipjack tuna
(Katsuwonus pelamis). J. Fish. Res. Board
Can. 27:1637-1652.
- Magnuson, J. J.
1970. Hydrostatic equilibrium of Euthynnus
affinis, a pelagic teleost without a gas
bladder. *Copeia* 1970:56-85.
- Bardach, J. E., and J. Atema.
1971. The sense of taste in fishes. In L. M.
Beidler (editor), Handbook of sensory physi-
ology IV. Chemical senses 2. Taste, P.
293-336. Springer-Verlag, Berlin, Heidel-
berg, and N.Y.

- Muir, B. S., and C. E. Brown.
1971. Effects of blood pathway on the blood-pressure drop in fish gills, with special reference to tunas. *J. Fish. Res. Board Can.* 28:947-955.
- Stevens, E. D., and F. E. J. Fry.
1971. Brain and muscle temperatures in ocean caught and captive skipjack tuna. *Comp. Biochem. Physiol.* 38A:203-211.
- Cahn, P. H.
1972. Sensory factors in the side-to-side spacing and positional orientation of the tuna, *Euthynnus affinis*, during schooling. *Fish. Bull., U.S.* 70:197-204.
- Gordon, M. S.
1972. Comparative studies on the metabolism of shallow-water and deep-sea marine fishes. I. White-muscle metabolism in shallow-water fishes. *Mar. Biol.* 13:222-237.
1972. Comparative studies on the metabolism of shallow-water and deep-sea marine fishes. II. Red-muscle metabolism in shallow-water fishes. *Mar. Biol.* 15:246-250.
- Nakamura, E. L.
1972. Development and uses of facilities for studying tuna behavior. In H. E. Winn and B. L. Olla (editors), *Behavior of marine animals. Current perspectives in research*, vol. 2: Vertebrates, p. 245-277. Plenum Publ. Corp., N.Y.
- Neill, W. H., and T. C. Byles.
1972. Automatic pellet dispenser for experimental feeding of fishes. *Prog. Fish-Cult.* 34:170.
- Neill, W. H., J. J. Magnuson, and G. D. Chipman.
1972. Behavioral thermoregulation by fishes: A new experimental approach. *Science (Wash., D.C.)* 176:1433-1445.
- Stevens, E. D.
1972. The effect of changes in ambient temperature on spontaneous activity in skipjack tuna. *Comp. Biochem. Physiol.* 42A:803-805.
1972. Some aspects of gas exchange in tuna. *J. Exp. Biol.* 56:809-823.
- Tamura, T., I. Hanyu, and H. Niwa.
1972. Spectral sensitivity and color vision in skipjack tuna and related species. *Bull. Jpn. Soc. Sci. Fish.* 38:799-802.
- Hanyu, I., T. Tamura, and H. Niwa.
1973. Electroretinograms and retinal ganglion cell responses in the skipjack tuna. *Bull. Jpn. Soc. Sci. Fish.* 39:265-273.
- Magnuson, J. J.
1973. Comparative study of adaptations for continuous swimming and hydrostatic equilibrium of scombroid and xiphooid fishes. *Fish. Bull., U.S.* 71:337-356.
- Steffel, S.
1973. Temperature discrimination thresholds in a tuna, the kawakawa (*Euthynnus affinis*), as determined by operant conditioning. M.S. Thesis, Univ. Wisconsin, Madison, 52 p.
- Dizon, A. E., E. D. Stevens, W. H. Neill, and J. J. Magnuson.
1974. Sensitivity of restrained skipjack tuna (*Katsuwonus pelamis*) to abrupt increases in temperature. *Comp. Biochem. Physiol.* 49A: 291-299.

- Neill, W. H., and E. D. Stevens.
1974. Thermal inertia versus thermoregulation in "warm" turtles and tunas. Science (Wash., D.C.) 184:1008-1010.
- Dizon, A. E., T. C. Byles, and E. D. Stevens.
1976. Perception of abrupt temperature decrease by restrained skipjack tuna, Katsuwonus pelamis. J. Therm. Biol. 1:185-187.
- Neill, W. H., R. K. C. Chang, and A. E. Dizon.
1976. Magnitude and ecological implications of thermal inertia in skipjack tuna, Katsuwonus pelamis (Linnaeus). Environ. Biol. Fish. 1:61-80.
- Steffel, S., A. E. Dizon, J. J. Magnuson, and W. H. Neill.
1976. Temperature discrimination by captive free-swimming tuna, Euthynnus affinis. Trans. Am. Fish. Soc. 105:588-591.
- Dizon, A. E.
1977. Effect of dissolved oxygen concentration and salinity on swimming speed of two species of tunas. Fish. Bull., U.S. 75:649-653.
- Dizon, A. E., W. H. Neill, and J. J. Magnuson.
1977. Rapid temperature compensation of voluntary swimming speeds and lethal temperature in tropical tunas (Scombridae). Environ. Biol. Fish. 2:83-92.
- Iversen, R. T. B., and J. O. Puffinburger.
1977. Capture, transportation, and pumping of threadfin shad, Dorosoma detense. In R. S. Shomura (editor), Collection of tuna baitfish papers, p. 127-136. U.S. Dep. Commer., NOAA Tech. Rep. FTS Circ. 408.
- Kitchell, J. F., J. J. Magnuson, and W. H. Neill.
1977. Estimation of caloric content for fish biomass. Environ. Biol. Fish. 2:185-188.
- Barkley, R. A., W. H. Neill, and R. M. Gooding.
1978. Skipjack tuna, Katsuwonus pelamis, habitat based on temperature and oxygen requirements. Fish. Bull., U.S. 76:653-662.
- Barry, M.
1978. Behavioral response of yellowfin tuna, Thunnus albacares, and kawakawa, Euthynnus affinis, to turbidity. M.S. Thesis, Univ. Hawaii, Honolulu, 31 p. + tables.
- Bone, Q.
1978. III. Myotomal muscle fiber types in Scomber and Katsuwonus. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 183-205. Acad. Press, N.Y.
- Brill, R. W.
1978. V. Temperature effects on speeds of muscle contraction and stasis metabolic rate. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 277-283. Acad. Press, N.Y.
- Brill, R. W., D. L. Guernsey, and E. D. Stevens.
1978. IV. Body surface and gill heat loss rates in restrained skipjack tuna. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 261-276. Acad. Press, N.Y.
- Dizon, A. E., R. W. Brill, and H. S. H. Yuen.
1978. III. Correlations between environment, physiology, and activity and the effects on thermoregulation in skipjack tuna. In G. D.

- Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 233-259. Acad. Press, N.Y.
- Dizon, A. E., and G. D. Sharp.
1978. II. Perspectives: The past, present, and future of tuna physiology. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 451-458. Acad. Press, N.Y.
- Guppy, M., and P. W. Hochachka.
1978. Controlling the highest lactate dehydrogenase activity known in nature. Am. J. Physiol. 234:R136-R140.
1978. II. Skipjack tuna white muscle: A blueprint for the integration of aerobic and anaerobic carbohydrate metabolism. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 175-181. Acad. Press, N.Y.
- Hochachka, P. W., W. C. Hulbert, and M. Guppy.
1978. I. The tuna power plant and furnace. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 153-174. Acad. Press, N.Y.
- Ikehara, W., J. Atema, A. Brittain, J. Bardach, A. Dizon, and K. Holland.
1978. Reactions of yellowfin tuna to prey scents. (Abstr.) Pac. Sci. 32:97.
- Kitchell, J. F., W. H. Neill, A. E. Dizon, and J. J. Magnuson.
1978. III. Bioenergetic spectra of skipjack and yellowfin tunas. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 357-368. Acad. Press, N.Y.
- Magnuson, J. J.
1978. Locomotion by scombrid fishes: Hydro-mechanics, morphology, and behavior. In W. S. Hoar and D. J. Randall (editors), Fish physiology, vol. VII, p. 240-315. Acad. Press, N.Y.
- Monckton, E. A.
1978. Stress in captive skipjack tuna, Katsuwonus pelamis. M.S. Thesis, Univ. Hawaii, Honolulu, 13 p. + tables.
- Brill, R. W.
1979. The effect of body size on the standard metabolic rate of skipjack tuna, Katsuwonus pelamis. Fish. Bull., U.S. 77:494-498.
1979. The thermal physiology of tuna. Ph.D. Dissertation, Univ. Hawaii, Honolulu, 215 p.
- Brill, R. W., and A. E. Dizon.
1979. Effect of temperature on isotonic twitch of white muscle and predicted maximum swimming speeds of skipjack tuna, Katsuwonus pelamis. Environ. Biol. Fish. 4:199-205.
1979. Red and white muscle fibre activity in swimming skipjack tuna, Katsuwonus pelamis (Linnaeus). J. Fish Biol. 15:679-685.
- Dizon, A. E., and R. W. Brill.
1979. Thermoregulation in tunas. Am. Zool. 19:249-265.
1979. Thermoregulation in yellowfin tuna, Thunnus albacares. Physiol. Zool. 52:581-593.
- Guppy, M., and P. W. Hochachka.
1979. Pyruvate kinase functions in hot and

- cold organs of tuna. *J. Comp. Physiol.* 129: 185-191.
- Atema, J., K. Holland, and W. Ikehara.
1980. Olfactory responses of yellowfin tuna (Thunnus albacares) to prey odors: Chemical search image. *J. Chem. Ecol.* 6:457-465.
- Gooding, R. M., W. H. Neill, and A. E. Dizon.
1981. Respiration rate and low-oxygen tolerance limits in skipjack tuna, Katsuwonus pelamis. *Fish. Bull.*, U.S. 79:31-48.
- Ikehara, W. N., and J. E. Bardach.
1981. Chemosensory attracting and guiding of yellowfin tuna, Thunnus albacares. *Southwest Fish. Cent. Admin. Rep.* LJ-81-07C, Natl. Mar. Fish. Serv., NOAA, La Jolla, CA 92038.
- Kashin, S. M., R. W. Brill, W. N. Ikehara, and A. E. Dizon.
1981. Induced locomotion by midbrain stimulation in restrained skipjack tuna, Katsuwonus pelamis. *J. Exp. Zool.* 216:327-329.
- Kaya, C. M., A. E. Dizon, and S. D. Hendrix.
1981. Induced spawning of tuna, Euthynnus affinis. *Fish. Bull.*, U.S. 79:185-187.
- Uchiyama, J. H., and P. Struhsaker.
1981. Age and growth of skipjack tuna, Katsuwonus pelamis, and yellowfin tuna, Thunnus albacares, as indicated by daily growth increments of sagittae. *Fish. Bull.*, U.S. 79:151-162.
- Jemison, H. A., III, A. E. Dizon, and M. M. Walker.
1982. An automatic feeder for liquids, or wet or dry solids. *Behav. Res. Methods Instrum.* 14:54-55.
- Kaya, C. M., A. E. Dizon, S. D. Hendrix, T. K. Kazama, and M. K. K. Queenth.
1982. Rapid and spontaneous maturation, ovulation, and spawning of ova by newly captured skipjack tuna, Katsuwonus pelamis. *Fish. Bull.*, U.S. 80:393-396.
- Walker, M. M.
1982. Conditioned response for use in magnetic sensory discrimination studies in yellowfin tuna, Thunnus albacares. (Abstr.) Tenth Annual Conference of the International Marine Animal Trainers Association (IMATA), Honolulu, Hawaii, October 25-29, 1982. (Mimeo.)
- Walker, M. M., A. E. Dizon, and J. L. Kirschvink.
1982. Geomagnetic field detection by yellowfin tuna. *Oceans 82*, p. 755-758. Conference sponsored by Marine Technology Society, IEEE Council on Oceanic Engineering, Wash., D.C., September 20-22, 1982.
- Walker, M. M.
In press [1982]. Magnetic sensitivity in yellowfin tuna (Thunnus albacares). (Abstr.) *Pac. Sci.*
- In press [1983]. The likely site of magnetic sense organ in yellowfin tuna (Thunnus albacares) and blue marlin (Makaira nixiricans). (Abstr.) *Pac. Sci.*
- In press [1984]. Magnetic sensitivity and its possible physical basis in the yellowfin tuna Thunnus albacares. NATO Advanced Re-

search Institute, Mechanisms of Migration in Fishes.

In press [1984]. Single domain magnetite crystals and their possible arrangement in magnetoreceptor organelles in the yellowfin tuna (Thunnus albacares). (Abstr.) Pac. Sci.

Chang, R. K. C., B. M. Ito, A. E. Dizon, and W. H. Neill.

Temperature independence of metabolism and activity in skipjack tuna, Katsuwonus pelamis. Manuscr. in prep. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.

Kaya, C. M., M. K. K. Queenth, and A. E. Dizon.

A capture and restraining technique for biopsying small tuna. Manuscr. in prep. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.

Kirschvink, J. L., and M. M. Walker.

Particle-size considerations for magnetite-based magnetoreceptors. Manuscr. in prep. In J. L. Kirschvink, D. S. Jones, and B. J. MacFadden (editors), Magnetite biomineralization and magnetoreception in organisms: A new magnetism. Plenum Publ. Corp., N.Y.

Kirschvink, J. L., M. M. Walker, A. E. Dizon, and K. A. Peterson.

Interacting single domain magnets in the head of the chinook salmon, Oncorhynchus nerka. Manuscript submitted to J. Comp. Physiol.

Walker, M. M., J. L. Kirschvink, R. S. B. Chang, and A. E. Dizon.

A candidate magnetic sense organ in the yellowfin tuna, Thunnus albacares. Manuscr. in prep. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.

Walker, M. M., J. L. Kirschvink, and A. E. Dizon.

Magnetoreception and biomineralization of magnetite: Fish. In J. L. Kirschvink, D. S. Jones, and B. J. MacFadden (editors), Magnetite biomineralization and magnetoreception in organisms: A new magnetism. Plenum Publ. Corp., N.Y.

Walker, M. M., A. Perry, A. E. Dizon, and J. L. Kirschvink.

Detection, extraction, and characterization of biogenic magnetite. In J. L. Kirschvink, D. S. Jones, and B. J. MacFadden (editors), Magnetite biomineralization and magnetoreception in organisms: A new magnetism. Plenum Publ. Corp., N.Y.



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STATUS REVIEW DOCUMENT FOR PACIFIC SEA TURTLES¹

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September 1983

¹This report was completed in May 1983. Bound copies of the papers and correspondence listed in this report are on file in the library of the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P. O. Box 3830, Honolulu, Hawaii 96812.

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BACKGROUND

The purpose of this document is to consolidate all literature and correspondence relevant to Pacific sea turtles since 1978 to provide a biological basis for reviewing the status of the populations. The green, Chelonia mydas, loggerhead, Caretta caretta, and olive ridley, Lepidochelys olivacea, sea turtles were listed in 1978 under the Endangered Species Act (ESA) after 4-1/2 years of evaluations. This initial period culminated in the publication of a Final Environmental Impact Statement (FEIS). The specific action, as stated in the FEIS, was as follows:

"On the basis of the best scientific and commercial data available to NMFS and FWS, the green, loggerhead, and Pacific ridley sea turtles have suffered serious declines, and are thought likely to become endangered species within the foreseeable future throughout a significant portion of their ranges. Consequently the NMFS and the FWS will list and protect these three species under the Endangered Species Act of 1973 (16 U.S.C. 1531-1543) in the following manner: The loggerhead is to be listed as threatened throughout its range. The Pacific ridley is to be listed as threatened throughout its range except for the breeding colony population found on the Pacific coast of Mexico which will be listed as endangered. The green turtle is to be listed as threatened throughout its range except for the breeding colony populations found in Florida and on the Pacific coast of Mexico which will be listed as endangered."

Under "Alternatives to the Action," the FEIS further stated that:

"To not list these animals and provide essential protection would be inconsistent with our responsibilities under the Act. This alternative was not a viable option."

Two other sea turtles in the Pacific, the hawksbill, Eretmochelys imbricata, and the leatherback, Dermochelys coriacea, were listed as endangered under the ESA in 1971. A formal review of the status of these two species was conducted by the Fish and Wildlife Service (FWS) alone in 1979. Relevant literature and correspondence for these turtles in the Pacific dating from 1978 are contained as part of this present document.

The factors given in the FEIS that contributed to the decline of sea turtles, thereby making it necessary to list and protect them under the ESA, are as follows: 1) destruction, modification, or curtailment of habitat or range; 2) commercial overutilization; 3) natural predation and disease; 4) inadequacy of regulatory mechanisms; and 5) manmade factors affecting their existence--including incidental catch by fishermen.

Additional background information on the 1978 listing can be found in C28 of the correspondence dossier.

STATUS OVERVIEW

The most current, complete, and concise status overview presented to date for each of the five species can be found in reference 52 of the literature dossier. The published volume resulting from the World Conference on Sea Turtle Conservation (WCSTC), held in late 1979, contains a substantial number of papers providing a comprehensive and global perspective on biology, status, conservation theory, techniques, and law (33). Included as part of this book is a Sea Turtle Conservation Strategy (34) that was produced by the Conference. Two papers on the options and limitations in conserving sea turtles (47 and 75) describe much of the biological rationale for this conservation strategy.

A Marine Turtle Recovery Team has been established for the Atlantic, Gulf, and Caribbean areas of the United States. A draft recovery plan has been prepared (60) and, in 1982, was being circulated for review. The efforts of this recovery team, and the problems in general of recovering sea turtle populations, are described in 76.

GEOGRAPHICAL AREAS

Eastern Pacific

Sea turtles occur off the west coast of the United States, but very little seems to be known of their status (53, 54, 65, C13).

Papers presented at the WCSTC on the status of sea turtles off the Pacific coast of Mexico, Central and South America include 35, 40, 41, and 51. The FWS has carried out cooperative contracted research on olive ridleys nesting in Costa Rica (42), as well as on the ESA endangered green turtle breeding colony in Mexico (39). A preliminary report on the accidental capture of sea turtles by Mexican shrimp trawlers has also been completed for the FWS (38). An aerial survey of Michoacan on the Mexican Pacific coast has recently revealed nesting by leatherbacks in greater densities than previously documented. However, due to "severe stresses" on all major populations of this species, the author of the paper considers the "endangered" status still justified (78). Both current (51) and historical (49) information have also been published on the status of sea turtles in the Galapagos Islands of the eastern Pacific.

State of Hawaii

Overall accounts of sea turtles in the State of Hawaii (Hawaiian Archipelago) appear in 24 and 25. The green turtle is the most abundant species at this location. Complete summaries of the results of tagging and other research conducted on this population, including most historical aspects, are presented in 18 and 29. These two papers alone provide a

comprehensive review of nearly all available information. The bibliography in reference 18 contains 670 citations for Hawaiian sea turtles dating prior to September 1979. The conservation strategy of the WCSTC designated the Hawaiian green turtle breeding population at French Frigate Shoals as one of eight sea turtle colonies worthy of maximum protection by reason of isolation and unique ecology (basking behavior).

References to literature and correspondence found in the present document are listed as follows for specific aspects of the Hawaiian green turtle population.

Breeding population assessment: See report by Jerry A. Wetherall (1983). Assessment of the stock of green turtles nesting at East Island, French Frigate Shoals. Southwest Fisheries Center Administrative Report H-83-8, 22 p. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

Growth rates: Recently shown to be much slower in the wild than what occurs in captivity - 13, 15, 23, and 50; corroborated by workers in Australia (64); see also C1 for possible aging technique.

Habitat usage: A telemetry study determined that the breeding population heavily utilizes the inshore waters of French Frigate Shoals - 3 and 46.

Basking ecology: Increased understanding of the thermal ecology and behavior while basking on land - 95 and 96; more basking on Tern Island after closure of U.S. Coast Guard station - 81.

Migrations: Long distance movements regularly made by adult males and females between French Frigate Shoals and resident feeding areas throughout the Hawaiian chain - 15, 18, and 19; found to be one of the best documented when compared to tagging studies conducted elsewhere (71).

Tags and tagging techniques: Use of Inconel² alloy tags and multiple tags applied to each turtle reduces tag loss - 19 and 29; also discussed in 73. Experimental scute grafting offers promise for permanently marking hatchlings - 56, 57, 59.

Strandings and disease: Reported strandings on the increase, especially for turtles afflicted with fibrous papillomas - 55, 66, and 92; see also 18.

Predator controls: None instituted, but warranted for tiger sharks on a localized experimental basis; see 15 and 18.

²Use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Critical habitat designations: None to date, but terrestrial areas used for nesting and basking have been identified in 11; 46 establishes a biological basis for certain marine critical habitat at French Frigate Shoals.

Reproductive biology: Current research results appear in 29; see also 37 and 58 for an international perspective of the Hawaiian green turtle.

Enforcement: Efforts need to be enhanced to reduce illegal take and promote recovery - 25, 69, 93, and C11; State of Hawaii provided full legal protection in April 1982 after deleting 1974 fishery regulation (25, C3, and C21); however this appears to be nominal.

Educational efforts: Public needs to be better informed about the turtles' protected status, ecological requirements, and biological limitations, i.e., see 27.

Nesting habitat enhancement: Southwest Fisheries Center (SWFC) Honolulu Laboratory personnel break up old cement slab at French Frigate Shoals nesting area - 91.

Historical decline: Further information relevant to the main islands (12, 86, C19, C23, C25, and C26) and the Northwestern Hawaiian Islands (62).

Hawaiian cultural aspects: Unable to document use in ponds for fish culture enhancement - C18, C20, C22, and C27.

"Subsistence use" question: Historical overview and analysis given in 26a; also discussed in relation to Hawaii in 25, 68, C2, C3, C6, and C24.

Research needs: Outlined by the SWFC Honolulu Laboratory - 82; summarized by WCSTC - 34; not given priority in 1982 draft of FWS Pacific Islands Strategy Plan - C5.

Value to the ecosystem: Evidence that the green turtle can "short-circuit" the detritus cycle, thereby enhancing marine productivity - 89.

Hawksbills also occur in the State of Hawaii, but their range is limited to the main islands where they are present in relatively few numbers. Very little is known of their status since almost no research has been undertaken. Scattered nesting has been documented on the island of Hawaii (11), and apparently occurs regularly each year at the eastern end of Molokai (C10). Reference 18 contains a bibliography of the Hawaiian hawksbill for all literature prior to 1979.

Leatherbacks regularly occur in the offshore waters of the State of Hawaii where they are sighted by fishermen and sometimes become entangled in fishing gear (21 and 25; see also bibliography in 18). The recent stranding of a specimen on Oahu with all four flippers amputated (66), and an emergence on Maui, possibly for nesting (85), are the only records for

leatherbacks on shore in the Hawaiian Islands. Leatherbacks have recently been discovered in international waters northwest of the Hawaiian Islands (24) where they are impacted to an unknown degree by large drift nets set from foreign fishing vessels (22). Possible nesting areas for these turtles could be Malaysia, or the Pacific Mexican rookery described in 78.

Loggerheads are occasionally recorded in Hawaiian waters (25). One was recovered from the stomach of a tiger shark caught at Kure Atoll at the extreme northwest end of the chain (14). Olive ridleys, though relatively rare in Hawaiian waters, have been recorded in increasing numbers during recent years (25 and 66). Since several of these have been juvenile specimens, it is possible that pelagic waters surrounding the Hawaiian Islands serve as development habitat for the species. Since nesting by olive ridleys (as well as loggerheads) has never been found in Hawaii, the source of these young animals may very well be the ESA endangered breeding colony on the Pacific coast of Mexico.

American Samoa

A summary of all known sea turtle observations at uninhabited Rose Atoll is given in 28. No hawksbills have been found nesting at this location in recent years, and green turtles are only present in small numbers. Except for some scattered nesting by green turtles in the Manua Group, Rose Atoll is the sole breeding colony for this species throughout the entire Samoan Archipelago (American Samoa and Western Samoa). Other recent literature summarizing the status of sea turtles (greens and hawksbills) in Samoa consist of 4, 24, and 74. There are no laws controlling the taking of sea turtles in Western Samoa. A small hatchery project designed to restock hawksbills was operational for 10 years (24), but closed in late 1982.

The subject of subsistence use of sea turtles in American Samoa is discussed in 26a and C29.

Territory of Guam

The known status and conservation problems of Guam's sea turtles are summarized in 77. Green turtles appear to be the main species, but very little research has been conducted. Prior to the ESA listing in 1978, there were no regulatory controls on the taking of green turtles or their eggs on Guam (C16 and C17). However, in 1979 legal protection at the local government level was instituted through the "Endangered Species Act of Guam" (88). Some good efforts toward educating and informing the public about sea turtles have been initiated (1, 2, 10, 30, 31, 32, and C15).

Published reports on the home consumption of seafood (36) and patterns of marine exploitation (61) suggest only a minor and opportunistic interest by Guam residents in taking turtles (see also C8). A recently published Territory of Guam Fisheries Development and Management Plan does not mention sea turtles (5).

The Government of Guam is dissatisfied over the "subsistence use" exemption granted in 1978 to their close neighbors in the Northern Marianas, a part of the Trust Territory (U.N. trusteeship). Under the ESA listing, residents of the Trust Territory may take green turtles in the water for personal consumption "... if such taking is customary, traditional, and necessary for the sustenance of such resident and his immediate family." The apparent viewpoint taken by Guam is that for conservation laws to be effective, they need to be applied to the turtle's full range. Further information on this subject is given in 26a, C7, C12, and C16.

Trust Territory of the Pacific Islands

The most current and complete account of sea turtles throughout this area of the western Pacific appears in 77. No recent scientific explorations or research of sea turtles have been undertaken. The Trust Territory is a large area consisting of about 2,200 islands covering 2 million square miles of ocean with 140,000 native inhabitants, mostly Micronesians.

The traditional aspects of subsistence hunting for green turtles in the Caroline Islands are described in 70. Some traditions involving sea turtles at other locations in the Trust Territory are given in 61a and 69.

Recent records exist of sea turtles being taken by foreign longliners fishing in the Trust Territory (21). The magnitude of this catch is unknown.

In 1982 the Northern Marianas requested that the FWS provide assistance in the restoration of sea turtles (87). No actions are known to have been undertaken to date.

Other Areas

To the extent that it is known, the status of sea turtles is given in 24 for the U.S. Pacific islands of Howland, Baker, Jarvis, Johnston, Kingman Reef, and Wake. Plans have recently been announced for the construction of a major munitions disposal plant on Johnston at a coastal site where turtles frequently forage.

The current status of sea turtles at central and south Pacific islands not administered by the United States is described in 20, 24, 26, 79, 83, and 84.

BIBLIOGRAPHY OF PACIFIC SEA TURTLES, 1978-83

- *1. Alerta, C. 1981. Fish wardens hunt poachers. Pacific Daily News, 23 June.
- *2. Alerta, C. 1981. Feds enforce endangered species law. Pacific Daily News, 26 June.
- *3. Altonn, H. 1980. Transmitters reveal turtles way of life. Honolulu Star-Bulletin, 26 September, A:1.
- *4. Amerson, A. B., Jr. W. Whistler and T. Schwaner. 1982. Wildlife and wildlife habitat of American Samoa. II. Account of flora and fauna. U.S. Fish and Wildlife Service, Wash., D.C.
- 5. Amesbury, S. S., and P. Callaghan. 1981. Territory of Guam Fisheries Development and Management Plan. Territory of Guam, Office of the Governor, 99 p.
- *6. Anonymous. 1978. 4 are fined for fishing with chlorine. Honolulu Star-Bulletin, 14 October.
- *7. Anonymous. 1982. Don't blast fish. [From an open letter to the Director of Natural Resources.] Marianas Variety, Saipan, reprinted in Pacific Magazine, September-October, p. 9.
- *8. Anonymous. 1981. Marine fish may use tiny "magnets" to navigate. Marine Fisheries Review 43(3):25.
- *9. Anonymous. 1982. Sea turtles protected. The Honolulu Advertiser, 17 September.
- *10. Anonymous. 1983. Turtles return to sea. Pacific Daily News, 25 February.
- *11. Balazs, G. H. 1978. Terrestrial critical habitat for sea turtles under United States jurisdiction in the Pacific region. 'Elepaio 39(4):37-41.
- 12. Balazs, G. H. 1978. Sea turtles of Kahoolawe Island: A preliminary survey. University of Hawaii, Hawaii Institute of Marine Biology, Kaneohe, Report prepared for the U.S. Naval Facilities Engineering Command, Pearl Harbor, November, 21 p.
- *13. Balazs, G. H. 1979. Growth, food sources and migrations of immature Hawaiian Chelonia. Marine Turtle Newsletter 10:1-3.

*Bound copies of the papers and correspondence listed are on file in the library of the Honolulu Laboratory.

14. Balazs, G. H. 1979. Loggerhead turtle recovered from a tiger shark at Kure Atoll. 'Elepaio 39(12):145-147.
- *15. Balazs, G. H. 1980. A review of basic biological data on the green turtle in the Northwestern Hawaiian Islands. In R. W. Grigg and R. T. Pfund (editors), Proceedings of the Symposium on Status of Resource Investigations in the Northwestern Hawaiian Islands, April 24-25, 1980, University of Hawaii, Honolulu, Hawaii, p. 42-54. Sea Grant Misc. Rep. UNIHI-SEAGRANT-MR-80-04.
- *16. Balazs, G. H. 1980. Field methods for sampling the dietary components of green turtles. Chelonia mydas. Herpetological Review 11(1):5-6.
- *17. Balazs, G. H. 1980. Status of sea turtles in the Hawaiian Islands. Pacific Island Ecosystem Workshop Abstracts, Sea Grant Working Paper No. 45, University of Hawaii, p. 6.
- *18. Balazs, G. H. 1980. Synopsis of biological data on the green turtle in the Hawaiian Islands. NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFC-7, 141 p. (Also University of Hawaii Sea Grant Cooperative Report UNIHI-SEAGRANT-CR-81-02, 141 p.)
- *19. Balazs, G. H. 1982. Factors affecting the retention of metal tags on sea turtles. Marine Turtle Newsletter 20:11-14.
- *20. Balazs, G. H. 1982. Sea turtles and their traditional usage in Tokelau. A project report to the World Wildlife Fund and Office for Tokelau Affairs, March, 54 p.
- *21. Balazs, G. H. 1982. Annotated bibliography of sea turtles taken by longline fishing gear, 4 p.
- *22. Balazs, G. H. 1982. Driftnets catch leatherback turtles. Oryx 16(5):428-430. (HIMB Contribution No. 629.)
- *23. Balazs, G. H. 1982. Growth rates of immature green turtles in the Hawaiian Archipelago. In K. A. Bjorndal (editor), Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 117-125.
- *24. Balazs, G. H. 1982. Status of sea turtles in the central Pacific Ocean. In K. A. Bjorndal (editor), Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 243-252.
- *25. Balazs, G. H. 1982. Hawaii's fishermen help sea turtles. Hawaii Fishing News 7(11):8-9.
- *26. Balazs, G. H. 1982. Sea turtles: A shared resource of the Pacific Islands. The South Pacific Commission Fisheries Newsletter 23:22-24.

- *26a. Balazs, G. H. 1983. The issue of "subsistence" use of sea turtles at islands under United States jurisdiction in the Pacific. Draft manuscript, 10 p.
- *27. Balazs, G. H. 1983. Letter to the editor accompanying reproduction of poster "Sea Turtles of the World." Hawaii Fishing News 8(1):20-21.
- *28. Balazs, G. H., and W. Pedro. 1982. Historical summary of sea turtle observations at Rose Atoll, American Samoa, 5 p.
- *29. Balazs, G. H. In press. Recovery records of adult green turtles observed originally tagged at French Frigate Shoals, Northwestern Hawaiian Islands. NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFC. (Also University of Hawaii Sea Grant Cooperative Report.)
- *30. Beaver, J. 1981. Wildlife of Guam coloring book: Green sea turtle endangered species. Division of Aquatic and Wildlife Resources, Government of Guam.
- *31. Beaver, J. 1981. Warning: Stay clear of turtle shell. Pacific Daily News, 23 April.
- *32. Beaver, J. 1983. Roundabout Guam: Returning home. Panorama, 18 March.
- 33. Bjorndal, K. A. (editor). 1982. Biology and conservation of sea turtles: Proceedings of the World Conference on Sea Turtle Conservation. Smithsonian Institution Press, Wash., D.C., 583 p.
- *34. Bjorndal, K. A. (editor). 1982. Sea turtle conservation strategy. Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 567-583. (Abridged version reprinted in the South Pacific Commission Newsletter 21:8-15, August 1980.)
- *35. Brown, C. H., and W. M. Brown. 1982. Status of sea turtles in the southeastern Pacific: Emphasis on Peru. In K. A. Bjorndal (editor) Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 235-240.
- *36. Callaghan, P. 1978. Some factors affecting household consumption of seafood and fish products on Guam. Bureau of Planning, Economic Planning Division Technical Report No. 77-3, Government of Guam.
- *37. Carr, A. 1980. Some problems of sea turtle ecology. American Zoologist 20(3):489-498.
- *38. Cliffon, K. 1981. The accidental capture of sea turtles by Mexican shrimp trawlers on the Pacific coast of Mexico. Preliminary report to the Office of Endangered Species, U.S. Fish and Wildlife Service, 12 p.

- *39. Cliffton, K. 1982. Final report on the conservation of the east Pacific green turtle of North America, Chelonia mydas agassizi. Report submitted to the U.S. Fish and Wildlife Service, 35 p.
- *40. Cliffton, D. O., K. Cornejo, and R. S. Felger. 1982. Sea turtles of the Pacific coast of Mexico. In K. A. Bjorndal (editor) Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 199-209.
- *41. Cornelius, S. E. 1982. Status of sea turtles along the Pacific coast of middle America. In K. A. Bjorndal (editor) Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 211-219.
- *42. Cornelius, S. E., and D. C. Robinson. 1981. Abundance, distribution and movements of olive ridley sea turtles in Costa Rica. Final report, USFWS Project 14-16-0002-80-228, 28 p.
- *43. Dahl, A. L. 1980. Regional ecosystems survey of the South Pacific area: XII. Mariana Islands, p. 64-70. Technical Paper No. 179, South Pacific Commission, Noumea, New Caledonia.
- *44. Dahl, A. L. 1980. Regional ecosystems survey of the South Pacific area: XIII. Caroline Islands, p. 71-75. Technical Paper No. 179, South Pacific Commission, Noumea, New Caledonia.
- *45. Dahl, A. L. 1980. Regional ecosystems survey of the South Pacific area: XIV. Marshall Islands, p. 76-77. Technical Paper No. 179, South Pacific Commission, Noumea, New Caledonia.
- *46. Dizon, A. E., and G. H. Balazs. 1982. Radio telemetry of Hawaiian green turtles at their breeding colony. Marine Fisheries Review 44(5):13-20.
- *47. Ehrenfeld, D. 1982. Options and limitations in the conservation of sea turtles. In K. A. Bjorndal (editor) Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 457-463.
- *48. Fritts, T. H. 1981. Pelagic feeding habits of turtles in the eastern Pacific. Marine Turtle Newsletter 17:4-5.
- *49. Fritts, T. H. 1981. Marine turtles of the Galapagos Islands and adjacent areas of the eastern Pacific on the basis of observations made by J. R. Slevin, 1905-1906. J. Herpetology 15:293-301.
- *50. Gorman, J. 1981. Sea turtles in jeopardy. Discover 2(3):104-105.

- *51. Green, D., and F. Ortiz-Crespo. 1982. Status of sea turtle populations in the central eastern Pacific. In K. A. Bjorndal (editor) Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 221-233.
- *52. Groombridge, B. (compiler). 1982. The IUCN Amphibia-Reptilia Red Data Book, Part 1. Green turtle, p. 151-180; hawksbill turtle, p. 181-200; olive ridley, p. 209-223; leatherback, p. 224-241. IUCN, Gland, Switzerland.
- *53. Guess, R. C. 1981 and 1982. Marine mammal and seabird study, central and northern California: Sea turtle findings. Annual progress reports to the U.S. Department of the Interior.
- *54. Guess, R. C. 1982. Occurrence of a Pacific loggerhead turtle, Caretta caretta gigos Deraniyagala, in the waters off Santa Cruz Island, California. California Fish and Game 68(2):122-123.
- *55. Hastings, B. 1981. What's green and sick and should be left alone. The Honolulu Advertiser, 9 September.
- *56. Hendrickson, J. R., and L. P. Hendrickson. 1980. "Living tags" for sea turtles. Report to Southwest Fisheries Center, National Marine Fisheries Service, NOAA. Contract No. 80-ABH-00062.
- 57. Hendrickson, L. P., and J. R. Hendrickson. 1981. A new method for marking sea turtles? Marine Turtle Newsletter 19, p. 6-7.
- *58. Hirth, H. F. 1980. Some aspects of the nesting behavior and reproductive biology of sea turtles. American Zoologist 20(3):507-523.
- *59. Hodge, P. 1981. Baby sea turtles imported to boost local population. Windward Sun Press, 18 November.
- *60. Hopkins, S. R., and J. I. Richardson (editors). 1981. Recovery plan for marine turtles. Technical draft. Prepared by the Marine Turtle Recovery Team, 266 p. [only the Introduction is included in this dossier].
- *61. Jennison-Nolan, J. 1979. Guam: Changing patterns of coastal and marine exploitation. University of Guam Marine Laboratory Technical Report 59.
- 61a. Johannes, R. E. 1981. Words of the lagoon. University of California, Berkeley, 245 p.
- *62. Kam, A. K. H. In press. Research of the green turtle, Chelonia mydas, at Laysan Island, Lisianski Island, and Pearl and Hermes Reef, summer 1982. NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFC.

- *63. Kaser, T. 1982. Turtle adoptions delayed for health, home study. The Honolulu Advertiser, 27 July.
- *64. Limpus, C. 1979. Notes on growth rates of wild turtles. Marine Turtle Newsletter 10:3-5.
- 65. Maina, S. 1981. Partial list of records of marine turtles stranded along the west coast of the North America. Sean Bulletin (Smithsonian Institution), 6(7):16, 6(11):15, 6(12):14, 7(1):13.
- 66. Maina, S. 1981-82. Partial list of records of marine turtles stranded in the Hawaiian Islands. Sean Bulletin (Smithsonian Institution), 6(6):10, 6(9):14, 7(1):13, 7(4):18.
- *67. Manta Corporation. 1979. Tern Island Study Final Report. Vol. I, Threatened and endangered species, p. 134-155. Prepared on contract to the U.S. Department of the Interior, Fish and Wildlife Service.
- *68. Markrich, M. 1982. The green sea turtle--a threatened species. The Sunday Star-Bulletin and Advertiser, 31 October, A:14.
- *69. Matthews, L. B. 1982. Turtles and tradition. Glimpses of Micronesia and the western Pacific, 22(1):56-59.
- *70. McCoy, M. A. 1982. Subsistence hunting of turtles in the western Pacific: The Caroline Islands. In K. A. Bjorndal (editor), Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 275-280.
- *71. Meylan, A. B. 1982. Sea turtle migrations--evidence from tag returns. In K. A. Bjorndal (editor), Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 91-100.
- *72. Molina, H. F. 1979. Summary of marine turtle sightings made on aerial fishery surveys during fiscal years 1975 through 1979. Division of Aquatic and Wildlife Resources, Department of Agriculture, Government of Guam, Agana, Guam, 5 p. (abridged version contained in citation No. 77 by P. C. H. Pritchard).
- 73. Mrosovsky, N., and S. J. Shettleworth. 1982. What double tagging studies can tell us. Marine Turtle Newsletter 22:11-15.
- *74. Office of Marine Resources. 1979. Country statement--American Samoa. Joint SPC-NMFS Workshop on Marine Turtles in the Tropical Pacific Islands, WP. 15.
- *75. Pritchard, P. C. H. 1980. The conservation of sea turtles: Practices and problems. American Zoologist 20(3):609-617.

- *76. Pritchard, P. C. H. 1982. Recovered sea turtle populations and U.S. recovery team efforts. In K. A. Bjorndal (editor), Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 503-511.
- *77. Pritchard, P. C. H. 1982. Marine turtles of Micronesia. In K. A. Bjorndal (editor), Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 263-274.
- *78. Pritchard, P. C. H. 1982. Nesting of the leatherback turtle, Dermochelys coreacea in Pacific Mexico, with a new estimate of world population status. Copeia 1982(4):741-747.
- *79. Pritchard, P. C. H. 1982. Marine turtles of the South Pacific. In K. A. Bjorndal (editor), Biology and conservation of sea turtles. Smithsonian Institution Press, Wash., D.C., p. 253-262.
- 80. Pritchard, P. C. H., and eleven other authors. 1982. Sea turtle manual of research and conservation techniques. Prepared for the Western Atlantic Turtle Symposium, 95 p. (Second edition in press edited by K. A. Bjorndal and G. H. Balazs).
- *81. Sheekey, E. A. 1982. Green turtles basking on Tern Island, French Frigate Shoals. 'Elepaio 43(6):45-47.
- *82. Shomura, R. S. 1979. Summary report of the Planning Workshop for National Marine Fisheries Service Research on Marine Turtles in the Central and Western Pacific. Southwest Fisheries Center Administrative Report H-79-23, 13 p. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, Hawaii 96812.
- *83. South Pacific Commission. 1980. Joint SPC/NMFS workshop on marine turtles in the tropical Pacific Islands: Report of meeting. Noumea, New Caledonia, 11-14 December, 16 p.
- 84. Sternberg, J. 1981. The worldwide distribution of sea turtle nesting beaches. Center for Environmental Education, Wash., D.C. (no page numbers).
- *85. Stevens, T. 1982. Shells on beach no surprise, but this one's rare. Maui News, 14 September.
- *86. Telfer, T. C. 1979. A survey of the Na Pali Coast fauna and its habitat on the Island of Kauai-July 1979. Hawaii State Department of Land and Natural Resources.
- *87. Tenorio, P. A. 1982. Request for technical fishery and wildlife aids. Northern Mariana Islands.
- *88. Territory of Guam. 1979. The Endangered Species Act of Guam (P.L. 15-36). Section 12315.2, Agana, Guam.

- *89. Thayer, G. W., D. W. Engel, and K. A. Bjorndal. 1982. Evidence for short-circuiting of the detritus cycle of seagrass beds by the green turtle, Chelonia mydas L. Journal of Experimental Marine Biology and Ecology. 62:173-183.
- *90. Wexler, M. 1983. Treasured islands. National Wildlife 21(2):4-13.
- *91. Whitten, H. 1981. Scientists use brawn to assist sea turtles. Honolulu Star-Bulletin, 1 April, A:12.
- *92. Whitten, H. 1981. Turtle recuperating at Ala Wai Harbor. Honolulu Star-Bulletin, 27 August, A:10.
- *93. Whitten, H. 1982. Man still threatens scarce sea turtles. Honolulu Star-Bulletin, 17 September, A:17.
- *94. Whitten, H. 1982. Green sea turtle surprises the experts, nests on Oahu. Honolulu Star-Bulletin, 19 November, A:3
- *95. Whittow, G. C., and G. H. Balazs. 1979. The thermal biology of Hawaiian basking green turtles (Chelonia mydas). (Abstr.) American Zoologist 19(3):981.
- *96. Whittow, G. C., and G. H. Balazs. 1982. Basking behavior of the Hawaiian green turtle (Chelonia mydas). Pacific Science 36(2):129-139.

LIST OF CORRESPONDENCE

- C1. Bada, J. L. 1982. Letter, dated 19 October, to G. H. Balazs from Amino Acid Data Laboratory, Scripps Institution of Oceanography.
- C2. Balazs, G. H. 1978. Letter, dated 27 November, to R. B. Roe, Acting Director, Office of Marine Mammals and Endangered Species, National Marine Fisheries Service (NMFS), Wash., D.C.
- C3. Balazs, G. H. 1982. Memo, dated 21 March, to W. G. Gilmartin, Leader, Marine Mammals and Endangered Species Investigation, Southwest Fisheries Center, Honolulu Laboratory.
- C4. Balazs, G. H. 1982. Memo, dated 28 May, to W. G. Gilmartin, Leader, Marine Mammals and Endangered Species Investigation, Southwest Fisheries Center, Honolulu Laboratory.
- C5. Balazs, G. H. 1982. Letter, dated 28 May, to D. Coggeshall, Pacific Islands Administrator, U.S. Fish and Wildlife Service (review of draft USFWS Strategy Plan).
- C6. Balazs, G. H. 1982. Memo, dated 28 October, to W. G. Gilmartin, Leader, Marine Mammals and Endangered Species Investigation, Southwest Fisheries Center, Honolulu Laboratory.
- C7. Baldrige, M. 1981. Letter, dated 18 September, to P. M. Calvo, Governor of Guam, from the Secretary of Commerce, Wash., D. C.
- C8. Callaghan, P. 1982. Letter, dated 31 August, to G. H. Balazs from the University of Guam.
- C9. Dodd, C. K., Jr. 1982. Letter, dated 27 May, to G. H. Balazs from the Office of Endangered Species, Fish and Wildlife Service, Wash., D. C.
- C10. Dupre et al. 1981. Letter, dated 14 January, to G. H. Balazs from Halawa Valley, Molokai.
- C11. Fish and Wildlife Service. 1978. Memo, dated 14 December, from the Division of Law Enforcement, Honolulu office.
- C12. Gordon, W. G. 1981. Letter, dated 11 December, to P. M. Calvo, Governor of Guam, from the Assistant Administrator for Fisheries, Wash., D.C.
- C13. Guess, R. C. 1983. Letter, dated 11 January, to G. H. Balazs from the Center for Coastal Marine Studies, University of California, Santa Cruz.
- C14. Harter, J. 1981. Letter, dated 30 April, to G. H. Balazs from Jack Harter Helicopters, Lihue, Kauai.

- C15. Hosmer, A. J. 1983. Letter, dated 1 March, to G. H. Balazs from Aquatic and Wildlife Resources, Government of Guam.
- C16. Ikehara, I. I. 1973. Letter, dated 1 February, to G. H. Balazs from the Division of Fish and Wildlife, Government of Guam.
- C17. Ikehara, I. I. 1976. Letter, dated 19 March, to G. H. Balazs from the Division of Fish and Wildlife, Government of Guam.
- C18. Kikuchi, W. K. 1982. Letters, dated 13 April and 17 May, to G. H. Balazs from Kauai Community College.
- C19. Masaki, K. 1982. Letter, dated 7 April, to G. H. Balazs from Waimea, Kauai.
- C20. Nakagawa, S. 1982. Letter, dated 19 April, to G. H. Balazs from fish pond operator, Hilo, Hawaii.
- C21. Ono, S. 1981. Letter, dated 3 April, to G. H. Balazs from the Department of Land and Natural Resources, State of Hawaii.
- C22. Pakele, G. M. 1982. Letter, dated 16 September, to A. Cooper and Sons, Inc., Hilo, Hawaii, from the Hawaiian Legal Corporation.
- C23. Robinson, E. K. 1982. Letter, dated 17 September, to G. H. Balazs from Waimea, Kauai.
- C24. Roe, R. B. 1979. Letter, dated 13 February, to G. H. Balazs from Office of Marine Mammals and Endangered Species, NMFS, Wash., D.C.
- C25. Sylva, R. D. 1982. Letter, dated 28 April, to G. H. Balazs from former turtle fisherman at Paia, Maui.
- C26. TenBruggencate, J. 1980. Letter, dated 29 April, to G. H. Balazs from Lihue, Kauai.
- C27. Thevenin, L. A. 1982-83. Letters, dated 28 April and 11 February, to G. H. Balazs from Puako, Hawaii.
- C28. Wallace, D. H. 1978. Memo, dated 13 January, to R. A. Frank, Administrator of NOAA, Wash., D.C.
- C29. Wass, R. C. 1981. Letter, dated 10 December, to G. H. Balazs from Office of Marine Resources, Government of American Samoa.

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AN ANALYSIS OF SOME FACTORS AFFECTING THE ABUNDANCE OF
BLUE MARLIN IN HAWAIIAN WATERS

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1-2-83

SEP 20 1983

Received at the National Marine Fisheries Service
Library
Honolulu, Hawaii

September 1983

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SUMMARY

A statistical model was constructed to study the effects of various factors on the abundance of blue marlin, Makaira nigricans, around the main Hawaiian Islands in the third quarter of the year. The model was based on historical records of Japanese longline effort and catch-per-unit-effort (CPUE), and a set of simple assumptions on blue marlin population dynamics.

Third quarter blue marlin CPUE in local waters was shown to be very highly correlated with blue marlin CPUE at the beginning of the year on the mid-Pacific blue marlin grounds south and southwest of Hawaii. The effects of other factors on local blue marlin abundance, such as foreign longlining effort during the first two quarters in local, adjacent, and mid-Pacific waters could not be estimated reliably.

The study confirmed that local abundance of blue marlin is dictated largely by events occurring outside the Fishery Conservation Zone (FCZ). Although benefits to domestic blue marlin fishers could be expected under certain conditions, the quantitative effects of excluding foreign longline vessels from the FCZ cannot be computed.

BACKGROUND AND PURPOSE

The development of measures to control the foreign catch of billfishes in the Fishery Conservation Zone (FCZ) is based primarily on the idea that foreign fishing vessels compete significantly with domestic vessels on the local grounds, or, in the outer reaches of the FCZ, intercept fish migrating to local grounds from more distant waters. To the extent that this concept is valid, domestic harvesters could benefit from the exclusion of foreign vessels from particular areas of the FCZ during the seasons when billfish are most abundant.

If billfish occurring locally were all homegrown fish, then excluding foreign vessels would unquestionably help local fishermen. But if the billfish taken in local waters originate elsewhere, or are part of wide-ranging populations, the expulsion of foreign longliners would not necessarily lead to higher local catch rates. If the displaced foreign vessels were redeployed in other regions of the billfish's range, they would still affect local catch rates by reducing the number of billfish migrating from those regions to local waters. The net impact of removing the competitors would depend on the relative concentrations of billfish in the various areas and their vulnerability to the foreign longline gear. Unfortunately, with our meager understanding of billfish biology and the effects of fishing, we have been unable to predict the results of exclusionary policies with much confidence. Previous studies, such as that by Lovejoy, have stressed that at best only general qualitative conclusions could be reached, and that even these were based more on assumptions than established facts.

This report summarizes our recent attempts to examine some of the ideas expressed above, with respect to blue marlin, Makaira nigricans, only. Our approach was to assemble the best fishery statistics available, construct a simple but logical conceptual model of local blue marlin abundance, and see what conclusions could be drawn. In particular, we considered the relationships between the abundance of blue marlin in Hawaiian waters during the third quarter of the year and several factors thought to affect it. These included the abundance of blue marlin in the mid-Pacific at the beginning of the year, recruitment to the stock during the first half of the year, and the amount of fishing effort applied to the stock in this same period.

TRENDS IN ANNUAL ABUNDANCE AND FISHING EFFORT

We assumed a single population of blue marlin occupying the central Pacific, whose geographical distribution changes seasonally. While blue marlin may be found in Hawaiian waters throughout the year, their abundance seems to reach a peak in the summer months. Presumably they migrate into local waters from the equatorial waters to the south and southwest.

If this is so, it should be reflected in the historical records of blue marlin abundance around the main Hawaiian Islands and in more distant waters. The only available sources of such information are the blue marlin catch-per-unit-effort (CPUE) statistics of domestic longliners, fishing around Hawaii, and the CPUE of Japanese tuna longline vessels operating throughout the range of the blue marlin stock. In the area of our concern, the vessels target on yellowfin tuna, Thunnus albacares, and bigeye tuna, T. obesus, and catch blue marlin and other species incidentally. If

systematic changes in tuna targetting have occurred over the years, the CPUE trends for blue marlin may not reflect actual changes in abundance. Having no recourse, we assume no changes in blue marlin catchability have occurred.

For purposes of this analysis, we defined three zones in the central Pacific assumed to encompass most of the blue marlin, and computed the historical trends of CPUE in each. The areas are:

Local - The two 5° squares surrounding the main Hawaiian Islands, from long. 155° to 160°W and lat. 15° to 25°N.

Adjacent - The seven 5° squares bordering on the local area to the east, south, and west.

Mid-Pacific - All remaining 5° squares in the region from long. 150°W to 150°E and lat. 10°S to 25°N.

The areas are depicted in Figure 1. The 5° square unit was used because this is the smallest area by which Japanese longline statistics are available. The 'local' area is equivalent to the FCZ, for all practical purposes, and roughly coincides with the area where the domestic longliners fish.

Within each area we compiled the historical records of blue marlin, yellowfin tuna, and bigeye tuna CPUE, averaged over the whole year, between 1956 and 1980. A complete record was available only for Japanese longlining. Domestic data were available only for 1959 to 1978.

Nominal fishing effort by the two gears was also computed for each area. The CPUE and effort statistics are listed in Tables 1 and 2. Note that the units are different for the two gear types. Domestic CPUE is in metric tons/trip, and effort is measured in number of vessel trips.

Japanese CPUE is in number of blue marlin caught/1,000 hooks fished and effort is in thousands of hooks fished. In the case of the mid-Pacific area, Japanese effort since 1966 was expanded to include estimated effort by other high-seas longliners (primarily Korean).

The trends in annual CPUE and effort data are also depicted, for blue marlin only, in Figures 2-5. The actual values are not shown. Instead, we have plotted the magnitude of each year's CPUE and effort relative to the 1978 figures.

The most interesting features of the annual plots are

1 - While mid-Pacific foreign effort has fluctuated, the most dramatic changes in longline effort have been in adjacent and local waters. Domestic longlining has gone steadily downhill, in terms of both CPUE and effort since 1959. Japanese longlining in local and adjacent waters mushroomed during the 1960', but has since tended to stabilize or decline.

2 - Blue marlin CPUE has tended to decline in all areas.

(However, in the early 1970's, the domestic blue marlin CPUE is biased downward because of underreporting.)

In terms of explaining changes in local blue marlin abundance, the annual plots make two points. First, our assumption of a common blue marlin stock supporting fisheries in the three areas is reasonable, since local CPUE statistics follow the same basic trends as those in the mid-Pacific. Second, barring colossal leaps in relative fishing power, rapidly declining nominal effort by any gear would enhance survival of blue marlin and probably increase CPUE. Therefore it appears that year-to-year changes

in abundance of blue marlin, even locally, are not affected by domestic longlining. (Within-year impacts would be expected.)

QUARTERLY PATTERNS

Other information emerges when the CPUE and effort statistics are compiled by quarters. These detailed data are given in Table 3, for blue marlin only. To simplify analysis further, we averaged the quarterly data over all years, and plotted the resulting CPUE and effort statistics in Figures 6-9. Again, relative values are plotted, with the third quarter (July-September) taken as the base period.

All the quarterly plots suggest an increase in apparent abundance (or availability) of blue marlin in the third quarter, but especially those for adjacent and local areas. This supports the assumption that during the first half of the year blue marlin migrate into local waters from a major distribution center south and southwest of the main islands.

MODEL OF LOCAL BLUE MARLIN ABUNDANCE

On the basis of trends and patterns revealed in the annual and quarterly statistics, we constructed a simple model of local blue marlin abundance in the third quarter.

Logically, the model can be separated into three pieces. The first states that the local blue marlin abundance in the third quarter is equal to the mid-Pacific abundance during the third quarter times the proportion available in the local area in this season. This proportion is assumed to be constant or, at most, to vary from year to year in a random fashion. The second part states that the third-quarter abundance in the mid-Pacific

is equal to the mid-Pacific abundance at the beginning of the year times the proportion of those blue marlin surviving to the third quarter, plus all new blue marlin recruiting to the population during the first half of the year and still alive during the third quarter. The third piece of the model states that the survival rate during the first two quarters is a function of natural mortality factors (assumed constant) and fishing mortality on the stock (assumed proportional to foreign longlining effort in the local, adjacent, and mid-Pacific areas).

Mathematically inclined readers will find the model equation in the Appendix.

Of the factors in the model, the only ones known explicitly are the nominal fishing efforts. However, we made the usual assumption that CPUE is proportional to fish abundance, on the average, and substituted Japanese longline blue marlin CPUE statistics into the model. The third quarter local abundance in a given year was assumed to be proportional to the average of the Japanese CPUE's during the second, third, and fourth quarters in the local area. (The resulting statistic is called CPUEL.) The mid-Pacific abundance at the beginning of the year was assumed proportional to the average of the mid-Pacific Japanese CPUE's in the third and fourth quarters of the previous year and the first and second quarters of the current year. (The resulting statistic is denoted CPUEM.) Since third-quarter Japanese effort in local waters did not begin until 1962, we fit the model to data for 18 years, 1962-79 (1980 Japanese data have not yet been compiled on a quarterly basis). The data are listed in Table 4.

FITTING THE MODEL TO DATA

In fitting the model, the CPUE data were first converted to logarithms to satisfy mathematical requirements. For CPUEL and CPUEM, the converted values are denoted $\text{LOG}(\text{CPUEL})$ and $\text{LOG}(\text{CPUEM})$.

Figures 10 and 11 show that the transformed third quarter local abundance [$\text{LOG}(\text{CPUEL})$] is directly related to the transformed mid-Pacific abundance at the beginning of the year [$\text{LOG}(\text{CPUEM})$]. Of course, this was expected from the high correlation of local and mid-Pacific CPUE's in the annual data.

If $\text{LOG}(\text{CPUEM})$ is considered by itself as a predictor of $\text{LOG}(\text{CPUEL})$, we find that it can explain 80% of the year-to-year variation in $\text{LOG}(\text{CPUEL})$. The observed $\text{LOG}(\text{CPUEL})$ and the values predicted by information on $\text{LOG}(\text{CPUEM})$ alone are shown in Figure 12. Results in the original units are in Figure 13. In most years, the observed and predicted values are not far apart. However, the model tends to underestimate the observed values in the earlier years, and to overestimate them in more recent years. This would be expected to happen if the survival rate during the first two quarters, or the recruitment that occurs during this period, declined over the 18-year period.

In a second fitting stage, we therefore added the recruitment and survival components. We assumed that recruitment could either increase linearly, decrease linearly, or remain constant during the period. In the survival function, we assumed fishing mortality during the first two quarters was a linear combination of accumulated foreign longlining effort in the mid-Pacific, adjacent, and local waters.

When this more complete model was fit to the data, we found that it explained 95% of the annual variation in $\text{LOG}(\text{CPUE})$. The fitted model and the corresponding observed values are displayed in Figure 14. In the original units, results are shown in Figure 15.

Not surprisingly, recruitment was estimated to have declined over the years, and foreign effort was predicted as having a negative impact on blue marlin abundance in all three areas. These results are consistent with the significant negative correlations between foreign effort and blue marlin CPUE apparent in the annual summary plots, and the marked decline in blue marlin CPUE in all areas.

This statistical model may seem to be a successful explanatory device. However, this conclusion must be tempered, because the precision of the estimates of various effects is extremely low (see Appendix). Statistically, we could not reject the claim, for example, that foreign longlining has had no effect on blue marlin survival in the first two quarters.

Nor would the model be very satisfactory as a predictor. In the first place, the model is oversimplified. Secondly, as just noted, the parameters of the fitted model are poorly estimated. This is due in part to the dearth of data; only 18 years of data were available for estimating 6 unknown parameters. It is also due to linear dependencies between several of the independent variables. This means that while it may be logical to add the effort and recruitment components, it is not possible to statistically differentiate between their effects.

CONCLUSIONS

Despite the cautionary remarks, this modeling exercise has been beneficial. First, it has shown convincingly, if not conclusively, that the fate of local blue marlin fishing is dictated by events outside the FCZ. Year-to-year changes in local blue marlin catch rates tend to reflect similar changes in the mid-Pacific.

Second, the consistency among the various CPUE statistics suggests that they may be fairly good indicators of blue marlin abundance.

Third, the exercise has highlighted the inadequacy of our scientific understanding of blue marlin and our inability to clearly explain, much less forecast, changes in local abundance. This in spite of the fact that we used the best data available.

Although our analysis was different in character from the well-known Lovejoy simulation study, it shared some of the assumptions of that analysis, and substantiated others. It also had common objectives. As Lovejoy did with a compartmental migration model, we hoped to study the effects of excluding foreign longline effort from local waters. In our simple statistical model, no explicit assumptions were made about migration. However, if the effects of foreign fishing effort in the various areas had been estimated with enough precision, we could have made rough predictions of the net effects of excluding foreign vessels from the local area, under various assumptions about their redistribution in the other two areas (or outside all three areas). Our belief is that quantitative predictions are not yet possible. As Lovejoy concluded, the most that can be said is that some benefit will accrue, provided catchability of blue marlin by foreign longliners is constant. Needless to

say, a meaningful comparative study of alternative exclusionary policies in the FCZ would be out of the question.

APPENDIX

Let CPUEL = Japanese longline CPUE in local waters at middle of third quarter (average of second, third, and fourth quarter statistics).

CPUEM = Japanese longline CPUE in mid-Pacific waters at beginning of year (average of third and fourth quarter statistics of previous year and first and second quarter statistics of current year).

HL = Half of foreign longline effort in local waters during second quarter, plus half of third quarter effort.

HA = Total foreign longline effort in adjacent waters during first two quarters, plus half of third quarter effort.

HM = Total foreign longline effort in mid-Pacific waters during first two quarters, plus half of third quarter effort.

The complete nonlinear regression model is:

$$\ln(\text{CPUEL}) = A + \ln \{ \text{CPUEM} + C + D (\text{year} - 1962) \} \\ - B_1 \cdot \text{HM} - B_2 \cdot \text{HA} - B_3 \cdot \text{HL} + \epsilon$$

where the additional symbols are

C = Constant proportional to intercept of linear recruitment function

D = Constant proportional to slope of linear recruitment function

B_1 = Mid-Pacific area catchability coefficient

B_2 = Adjacent area catchability coefficient

B_3 = Local area catchability coefficient

A = Constant (includes natural mortality coefficient and other terms)

ϵ = Random error term

Estimates of model coefficients and their asymptotic standard errors:

Parameter	Estimate	Estimated standard error
A	-0.0876	2.98
C	-0.2082	3.47
D	-0.0227	0.192
B ₁	0.00000031	0.000037
B ₂	0.000040	0.00017
B ₃	0.00036	0.0014

$R^2 = 0.95$

Table 1.--Annual statistics of CPUE and nominal effort for domestic and Japanese longliners in local area. BM = blue marlin, YF = yellowfin tuna, BE = bigeye tuna.

Year	Domestic longline				Japanese longline			
	Effort	CPUE			Effort	CPUE		
		BM	YF	BE		BM	YF	BE
1956	--	--	--	--	215	0.455	10.502	25.531
1957	--	--	--	--	43	0.490	0.653	14.257
1958	--	--	--	--	37	0.543	1.656	10.998
1959	1,039	0.177	0.169	0.573	148	0.589	2.262	12.982
1960	879	0.144	0.156	0.645	300	0.872	4.647	14.240
1961	913	0.119	0.167	0.513	51	1.129	6.305	5.546
1962	761	0.095	0.145	0.720	399	1.400	2.612	14.352
1963	770	0.099	0.153	0.551	470	1.218	1.439	17.741
1964	730	0.082	0.182	0.519	1,614	0.659	2.594	12.212
1965	629	0.091	0.243	0.549	642	0.802	4.377	11.416
1966	614	0.085	0.259	0.563	466	0.984	2.248	10.434
1967	620	0.065	0.227	0.473	1,033	0.786	1.477	9.078
1968	514	0.061	0.192	0.497	1,181	0.633	2.901	6.554
1969	544	0.066	0.195	0.587	1,245	0.446	2.700	10.631
1970	566	0.064	0.444	0.380	966	1.009	6.415	8.635
1971	597	0.012	0.320	0.357	663	0.353	6.191	11.996
1972	501	--	0.286	0.450	618	0.325	3.333	8.088
1973	460	0.009	0.192	0.394	1,293	0.169	2.126	8.625
1974	385	0.016	0.326	0.481	2,618	0.384	2.630	7.363
1975	373	0.012	0.226	0.402	704	0.124	2.258	5.573
1976	471	0.016	0.236	0.412	1,658	0.165	2.574	9.179
1977	437	0.026	0.402	0.516	1,418	0.258	2.773	10.958
1978	503	0.037	0.341	0.376	1,629	0.550	0.604	11.739
1979	--	--	--	--	686	0.214	3.637	8.341
1980	--	--	--	--	263	0.236	1.472	8.000

Units: Japanese Effort = 1,000's of hooks

CPUE = Number of fish per 1,000 hooks

Domestic Effort = Number of trips

CPUE = Metric tons per trip

Table 2.--Annual statistics of CPUE and nominal effort for Japanese longliners in adjacent and mid-Pacific areas. BM = blue marlin, YF = yellowfin tuna, BE = bigeye tuna.

Year	Effort	Adjacent area			Effort	Mid-Pacific area		
		CPUE				CPUE		
		BM	YF	BE		BM	YF	BE
1956	227	0.666	0.683	16.676	26,785	2.768	16.315	10.592
1957	120	0.740	1.256	21.373	45,971	3.088	21.175	10.280
1958	505	1.113	1.273	25.308	48,124	2.906	20.090	14.291
1959	1,237	0.512	2.751	21.006	50,975	2.182	18.221	10.731
1960	1,581	1.278	3.755	18.356	52,038	1.989	22.751	8.532
1961	2,462	2.054	3.082	23.938	68,854	2.263	17.453	9.078
1962	5,596	1.702	1.413	26.652	71,412	2.121	14.951	6.086
1963	5,864	1.748	0.914	17.551	84,088	1.606	15.158	7.939
1964	7,561	0.929	1.639	12.221	66,815	1.554	15.935	7.639
1965	1,767	1.143	2.498	8.557	66,208	1.229	12.375	7.087
1966	2,283	0.993	1.429	13.516	68,098	1.260	18.370	6.332
1967	3,204	0.980	1.178	13.558	57,390	1.359	10.370	6.425
1968	3,970	0.698	1.507	8.272	54,260	1.091	13.107	5.325
1969	2,311	0.789	2.076	9.459	57,086	1.291	13.580	7.014
1970	7,365	1.227	3.917	8.742	61,140	1.593	12.758	5.562
1971	3,888	0.576	2.077	8.532	61,793	0.865	10.448	6.270
1972	5,088	0.854	1.407	9.615	79,229	1.025	10.322	7.694
1973	6,133	0.492	1.207	9.229	57,991	0.899	10.510	6.140
1974	3,462	0.568	1.462	7.340	65,601	0.809	5.313	6.807
1975	4,023	0.296	1.247	8.325	57,027	0.479	5.825	7.396
1976	5,305	0.459	1.123	8.752	55,448	0.719	9.050	7.186
1977	3,438	0.290	1.076	9.481	59,343	0.768	14.535	8.003
1978	7,392	0.538	0.867	10.240	54,276	0.828	17.287	6.720
1979	4,743	0.406	2.043	7.697	75,488	0.644	12.464	7.200
1980	4,977	0.535	1.265	9.862	93,390	0.752	14.132	5.828

Units: Japanese Effort = 1,000's of hooks

CPUE = Number of fish per 1,000 hooks

Table 3.--Quarterly statistics of blue marlin CPUE and nominal effort by domestic and Japanese longliners.

Year	Quarter	Domestic local		Japanese local		Japanese adjacent		Japanese mid-Pacific	
		Effort	CPUE	Effort	CPUE	Effort	CPUE	Effort	CPUE
1961	1	222	0.045	30	1.058	1,137	1.203	20,925	1.844
	2	228	0.110	21	1.228	1,244	2.629	18,599	2.326
	3	218	0.217	0	--	68	5.718	16,065	2.547
	4	245	0.107	0	--	10	2.043	13,263	2.492
1962	1	138	0.057	8	0.236	1,801	1.282	22,035	1.905
	2	207	0.110	361	1.416	3,445	1.783	16,079	2.190
	3	200	0.135	12	2.790	262	3.629	17,574	2.219
	4	216	0.067	16	0.544	86	1.369	15,723	2.243
1963	1	185	0.052	167	0.388	1,909	0.893	23,968	1.510
	2	194	0.113	242	1.767	3,629	2.156	22,461	1.663
	3	187	0.146	40	1.660	259	2.514	18,441	1.683
	4	204	0.082	19	0.560	65	0.981	19,215	1.584
1964	1	171	0.023	652	0.445	2,003	0.767	23,594	1.493
	2	183	0.056	779	0.740	4,739	1.047	17,179	1.782
	3	165	0.161	106	1.515	110	1.834	14,773	1.436
	4	211	0.091	75	0.464	706	0.454	11,267	1.488
1965	1	156	0.044	84	0.470	300	0.502	23,329	1.161
	2	159	0.124	462	0.828	743	1.361	21,535	1.223
	3	141	0.134	43	1.287	504	1.245	12,452	1.329
	4	173	0.066	50	0.707	219	1.039	8,890	1.279
1966	1	126	0.053	11	0.421	355	0.211	16,669	1.061
	2	152	0.093	439	0.985	1,533	1.104	20,684	1.231
	3	145	0.124	7	0.502	292	1.437	18,124	1.385
	4	191	0.068	6	2.462	101	0.756	12,620	1.399
1967	1	153	0.021	48	0.573	1,054	0.579	19,586	1.050
	2	141	0.080	911	0.763	1,818	1.096	18,020	1.554
	3	133	0.112	55	0.939	197	2.313	12,505	1.666
	4	193	0.056	17	2.101	134	0.581	7,277	1.161
1968	1	126	0.020	135	0.443	667	0.673	15,146	0.850
	2	121	0.071	915	0.691	2,750	0.741	17,692	1.357
	3	112	0.119	3	0.269	57	1.348	14,040	1.261
	4	155	0.045	126	0.426	493	0.415	7,379	0.621

Table 3.--Continued.

Year	Quarter	Domestic local		Japanese local		Japanese adjacent		Japanese mid-Pacific	
		Effort	CPUE	Effort	CPUE	Effort	CPUE	Effort	CPUE
1969	1	119	0.021	428	0.128	596	0.494	18,301	0.992
	2	121	0.052	320	0.871	518	1.003	15,788	1.349
	3	139	0.135	122	1.102	539	1.438	13,349	1.622
	4	165	0.049	373	0.230	656	0.352	9,645	1.305
1970	1	117	0.009	226	0.145	1,456	0.363	20,448	1.329
	2	129	0.049	183	1.593	3,609	1.533	14,847	1.991
	3	148	0.108	250	1.818	976	2.199	16,282	1.861
	4	172	0.073	304	0.633	1,322	0.623	9,562	1.083
1971	1	128	0.038	333	0.171	928	0.257	22,507	0.710
	2	142	0.015	50	0.530	1,420	0.794	16,684	0.822
	3	157	0.001	92	0.972	434	1.331	14,436	1.157
	4	170	0	186	0.322	1,104	0.267	8,164	0.863
1972	1	138	0	171	0.087	925	0.228	26,529	1.124
	2	120	0	160	0.575	2,361	0.768	21,675	1.086
	3	115	0	59	0.817	1,419	1.604	21,271	0.956
	4	128	0	226	0.198	382	0.109	9,751	0.770
1973	1	107	0	245	0.093	2,357	0.335	22,128	0.965
	2	111	0.002	506	0.191	2,881	0.552	12,773	0.969
	3	102	0.020	15	0.461	362	1.386	13,652	0.723
	4	140	0.012	525	0.175	532	0.248	9,437	0.901
1974	1	83	0.004	586	0.228	969	0.428	20,181	0.867
	2	92	0.014	1,106	0.454	1,207	0.726	17,371	0.976
	3	91	0.034	367	0.699	716	0.795	14,451	0.828
	4	119	0.011	557	0.200	568	0.181	13,595	0.484
1975	1	102	0.005	283	0.067	1,256	0.093	24,952	0.357
	2	83	0.008	236	0.152	1,599	0.322	8,137	0.565
	3	77	0.019	54	0.458	1,059	0.512	11,919	0.723
	4	111	0.015	129	0.053	107	0.158	12,017	0.432
1976	1	110	0.006	279	0.046	1,195	0.276	17,057	0.506
	2	97	0.011	1,122	0.178	1,859	0.411	15,035	0.856
	3	131	0.022	57	0.350	1,816	0.703	13,333	0.894
	4	133	0.021	198	0.206	433	0.140	10,022	0.642
1977	1	91	0.006	502	0.113	339	0.067	21,334	0.609
	2	97	0.022	442	0.212	2,178	0.267	12,409	0.794
	3	111	0.041	253	0.575	694	0.514	13,625	0.873
	4	138	0.026	219	0.314	226	0.154	11,973	0.902

Table 3.--Continued.

Year	Quarter	Domestic local		Japanese local		Japanese adjacent		Japanese mid-Pacific	
		Effort	CPUE	Effort	CPUE	Effort	CPUE	Effort	CPUE
1978	1	127	0.023	15	0	620	0.301	18,488	0.765
	2	126	0.044	709	0.383	4,452	0.539	13,744	1.076
	3	112	0.050	804	0.761	1,713	0.749	11,508	0.871
	4	138	0.028	99	0.111	605	0.175	10,534	0.563
1979	1	--	--	86	0.069	1,613	0.241	22,866	0.537
	2	--	--	351	0.273	2,619	0.517	20,069	0.753
	3	--	--	40	0.595	260	0.568	17,897	0.600
	4	--	--	207	0.101	249	0.120	14,653	0.713

Units: Japanese Effort = 1,000's of hooks
 CPUE = Number of fish per 1,000 hooks

Domestic Effort = Number of trips
 CPUE = Metric tons per trip

Table 4.--Data for fitting abundance models.
(Some data listed here were not used.)

Year	CPUED	CPUEL	CPUEM	HD	HL	HA	HM	HM (raised)
1960	0.259	1.6582	3.7939	200	150	1,525	36,168	36,168
1961	0.217	2.8864	4.8098	223	10	2,417	47,557	47,557
1962	0.135	2.5460	4.5677	204	187	5,378	46,901	46,901
1963	0.146	2.1779	3.8190	190	141	5,669	55,650	55,651
1964	0.161	1.6328	3.2717	174	443	6,799	48,160	48,160
1965	0.134	1.4851	2.6551	150	253	1,296	51,091	51,092
1966	0.124	1.8117	2.4509	149	224	2,035	46,415	48,736
1967	0.113	1.8720	2.6947	137	484	2,971	43,860	49,562
1968	0.119	1.0864	2.5176	116	460	3,447	39,859	42,649
1969	0.136	1.0970	2.1120	130	221	1,385	40,765	43,619
1970	0.108	1.7142	3.1243	138	217	5,554	43,436	49,083
1971	0.001	1.1797	2.2391	150	72	2,565	46,410	60,333
1972	0.000	0.9235	2.1159	118	110	2,997	58,841	76,494
1973	0.021	0.5839	1.8310	106	261	5,420	41,728	54,247
1974	0.034	0.6462	1.7349	92	737	2,535	44,719	53,735
1975	0.019	0.4370	1.1172	80	146	3,386	39,049	48,812
1976	0.022	0.3909	1.2589	114	590	3,963	38,759	50,387
1977	0.041	0.4976	1.4706	104	348	2,864	40,556	52,724
1978	0.050	0.5845	1.8092	119	757	5,930	37,987	49,383
1979	--	0.5182	1.3635	--	195	4,363	51,885	67,450

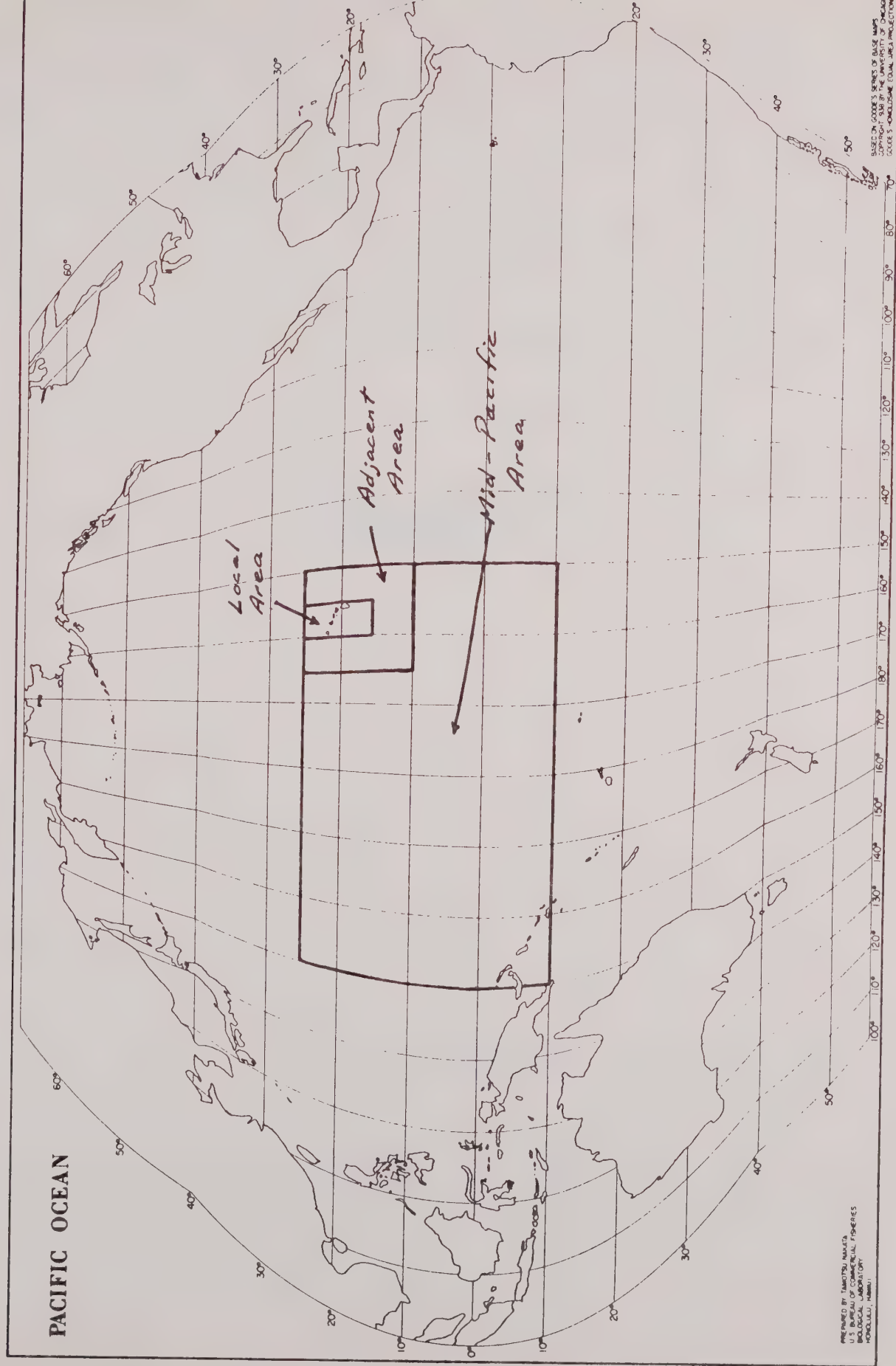


Figure 1

DOMESTIC LONGLINE

LOCAL AREA
 SPECIES: BLUE MARLIN
 CPUE = O EFFORT = X

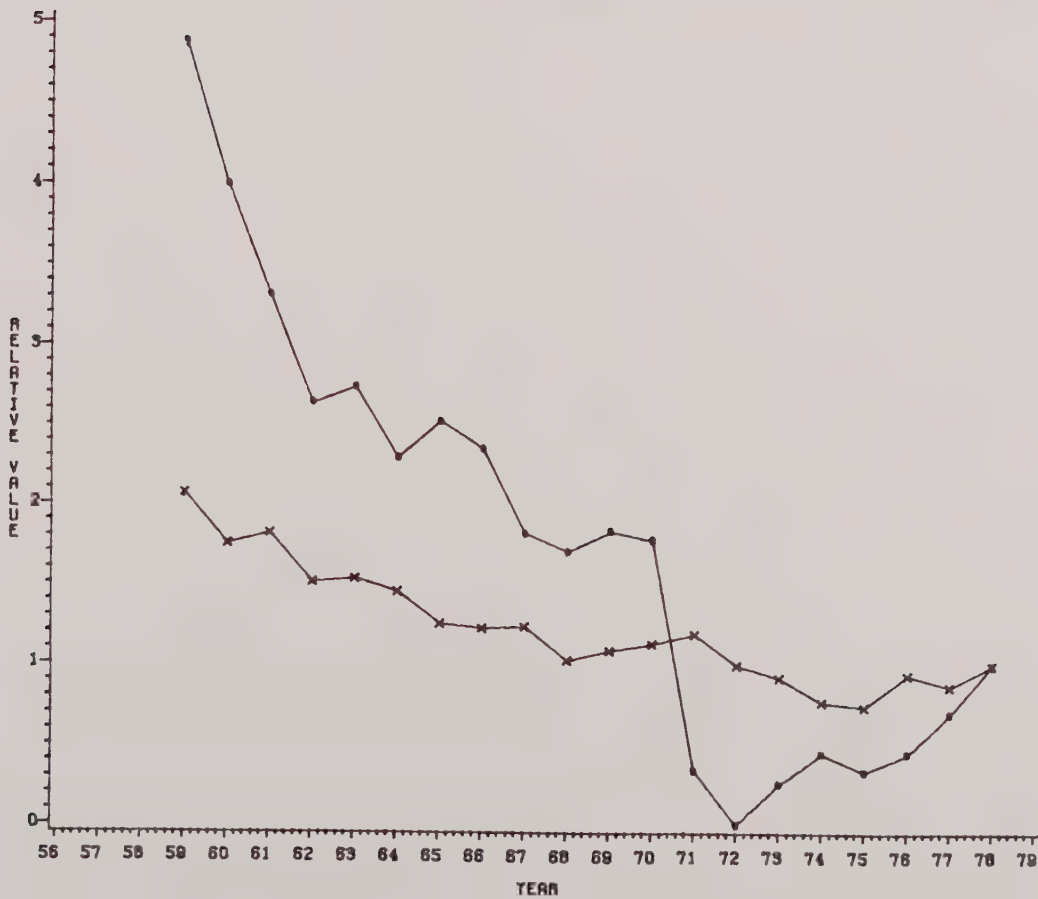


Figure 2.

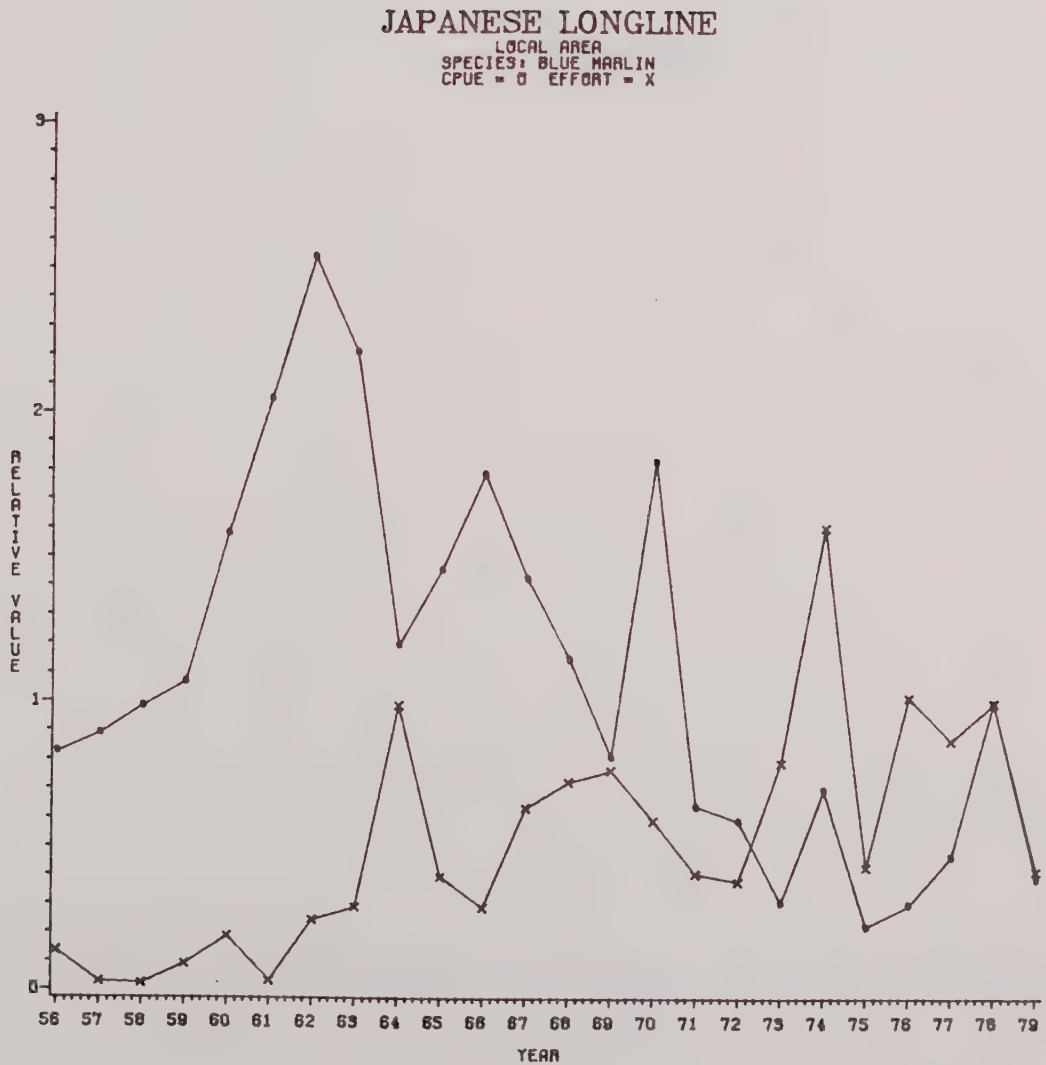


Figure 3.

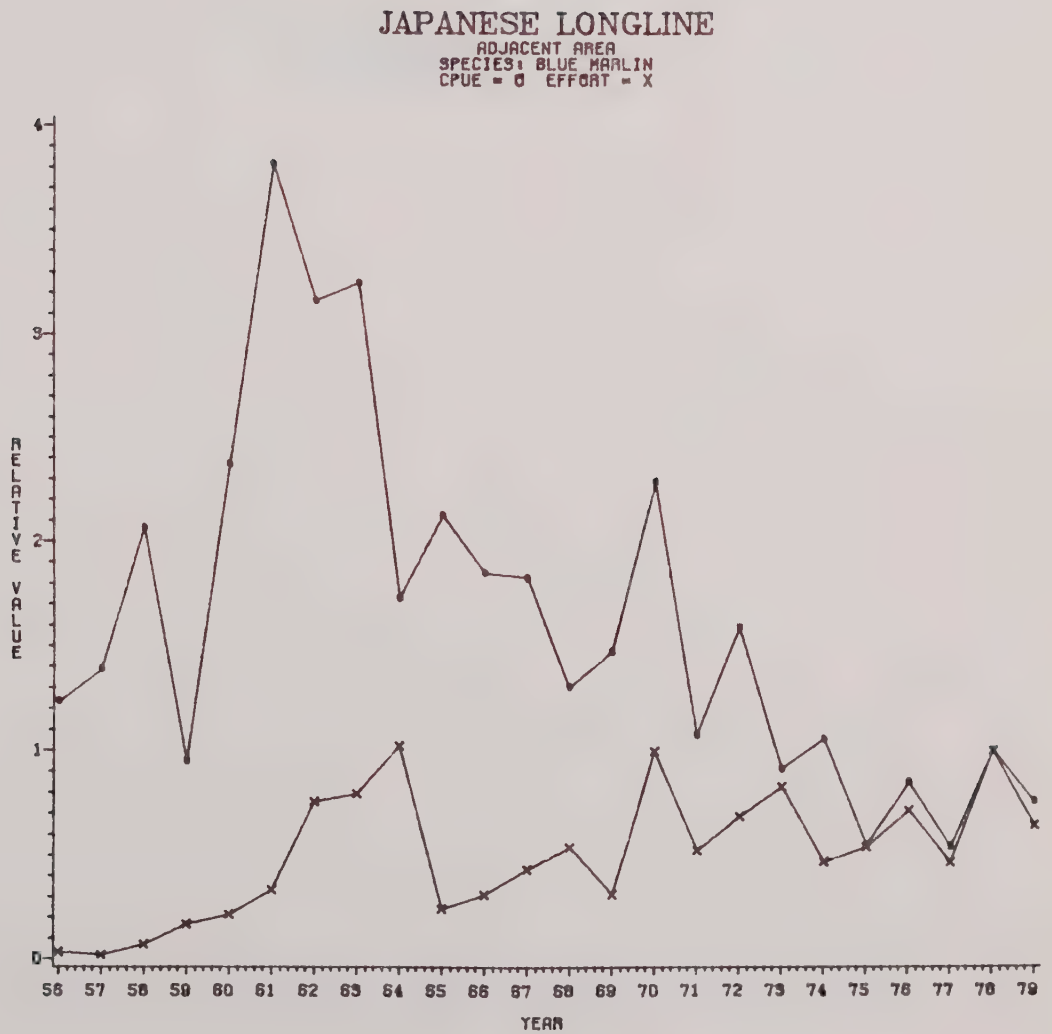


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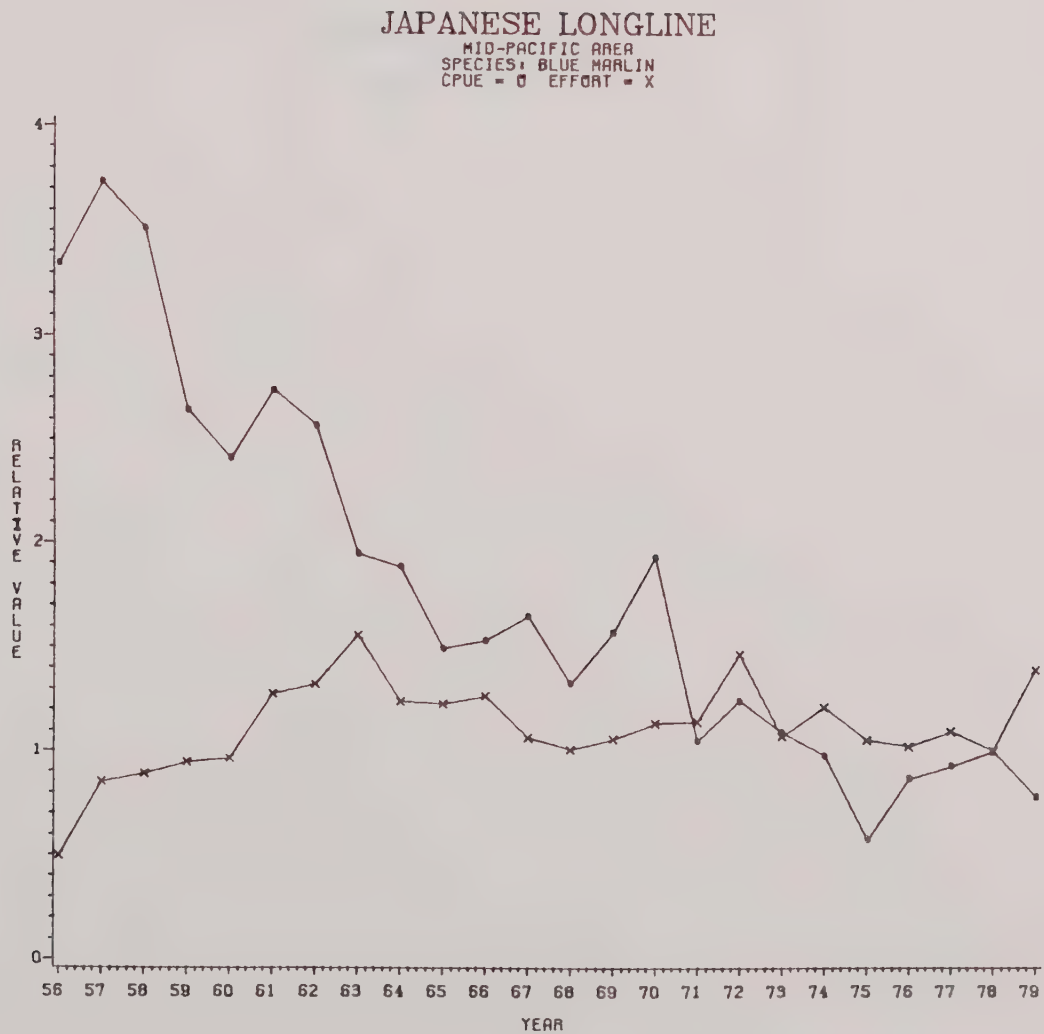


Figure 5.

DOMESTIC LONGLINE

LOCAL AREA
SPECIES: BLUE MARLIN
CPUE = 0 EFFORT = X

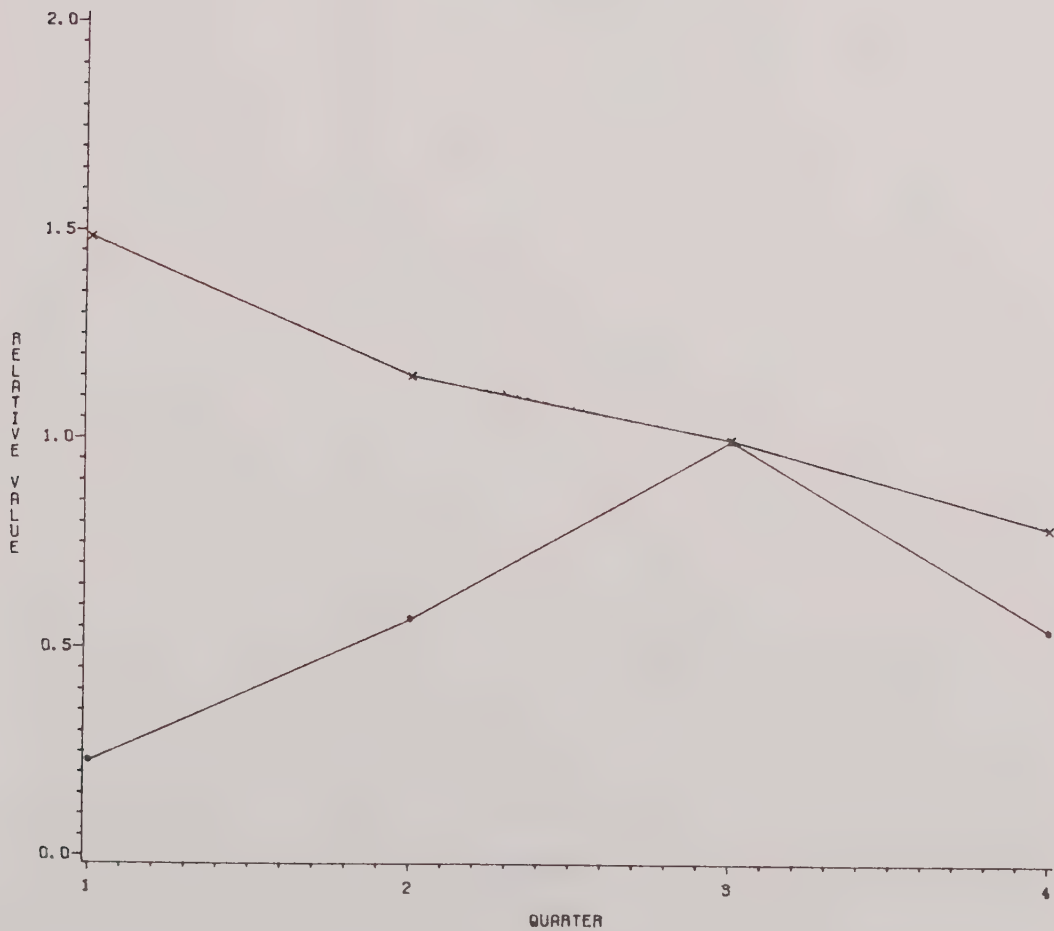


Figure 6.

JAPANESE LONGLINE

LOCAL AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X

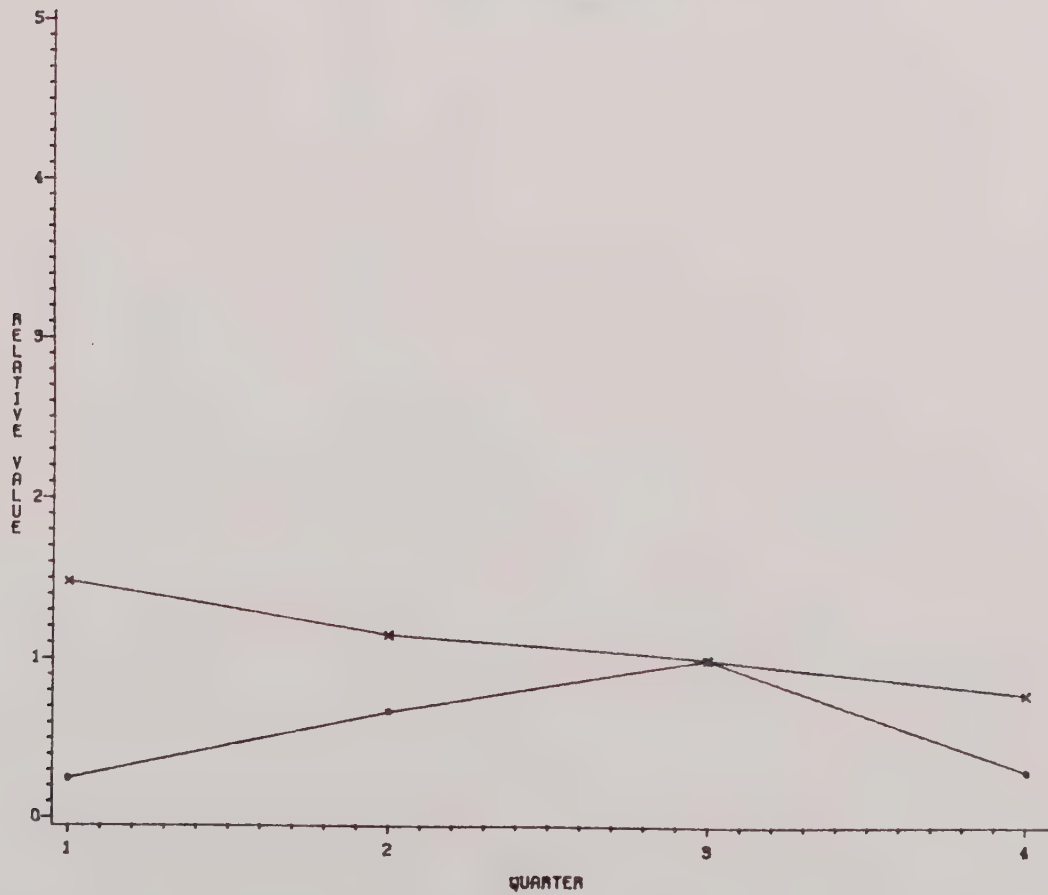


Figure 7.

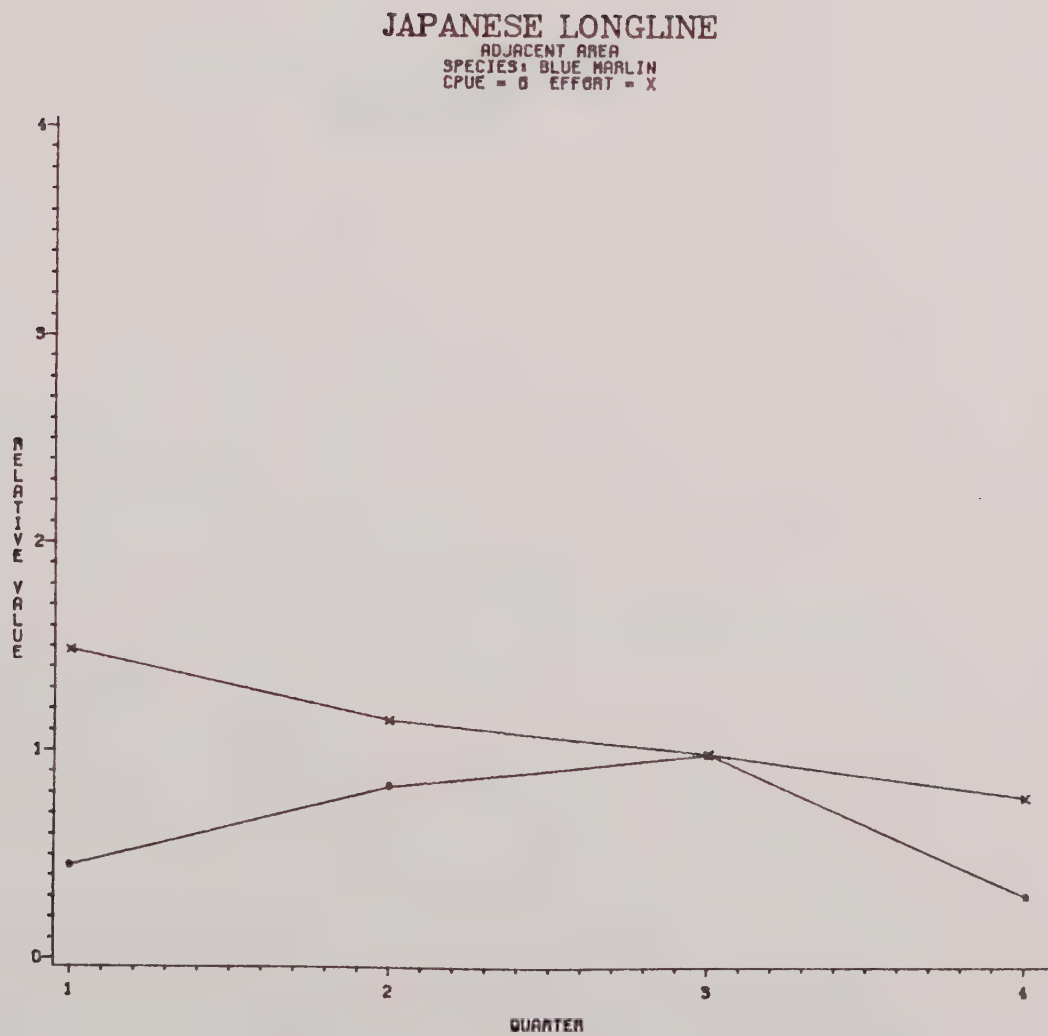


Figure 8.

JAPANESE LONGLINE

MID-PACIFIC AREA
SPECIES: BLUE MARLIN
CPUE = 0 EFFORT = X

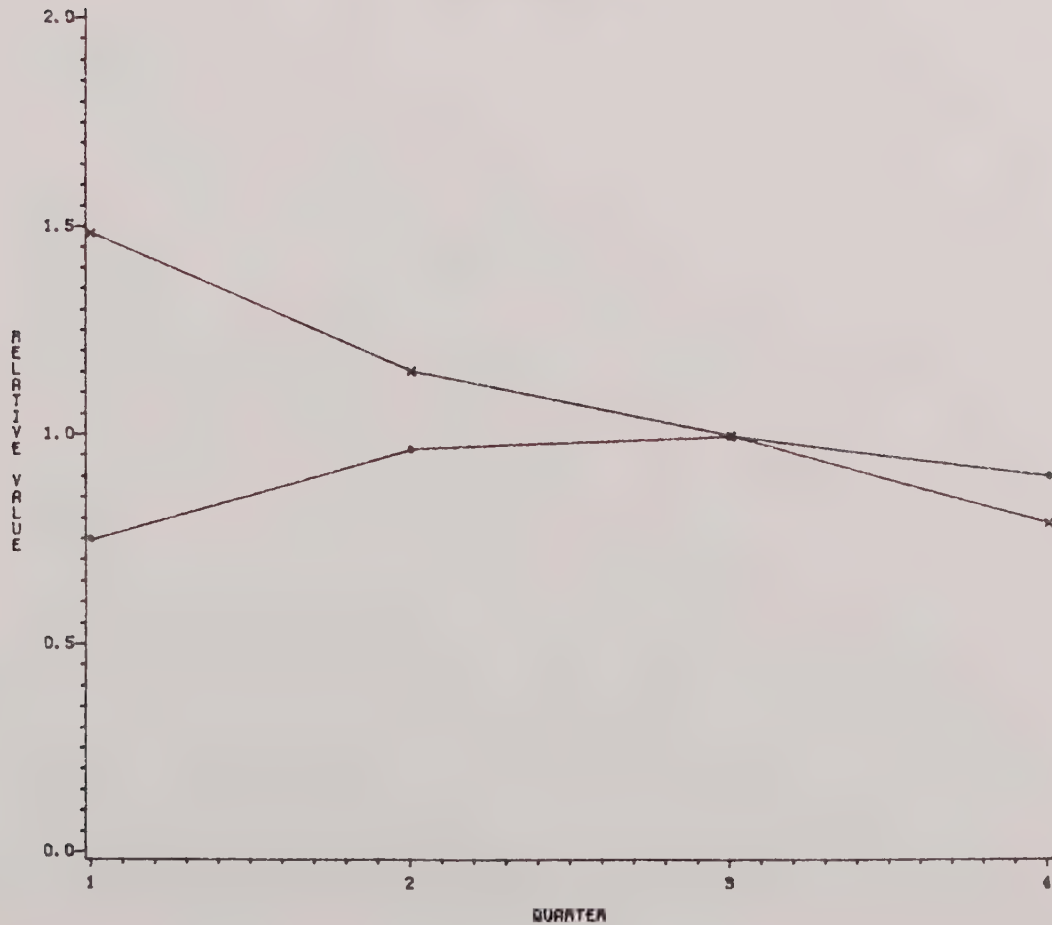


Figure 9.

JAPANESE LONGLINE LOG(CPUE)

o = LOCAL THIRD QUARTER (CPUE)
x = MID-PACIFIC START OF YEAR (CPUE)

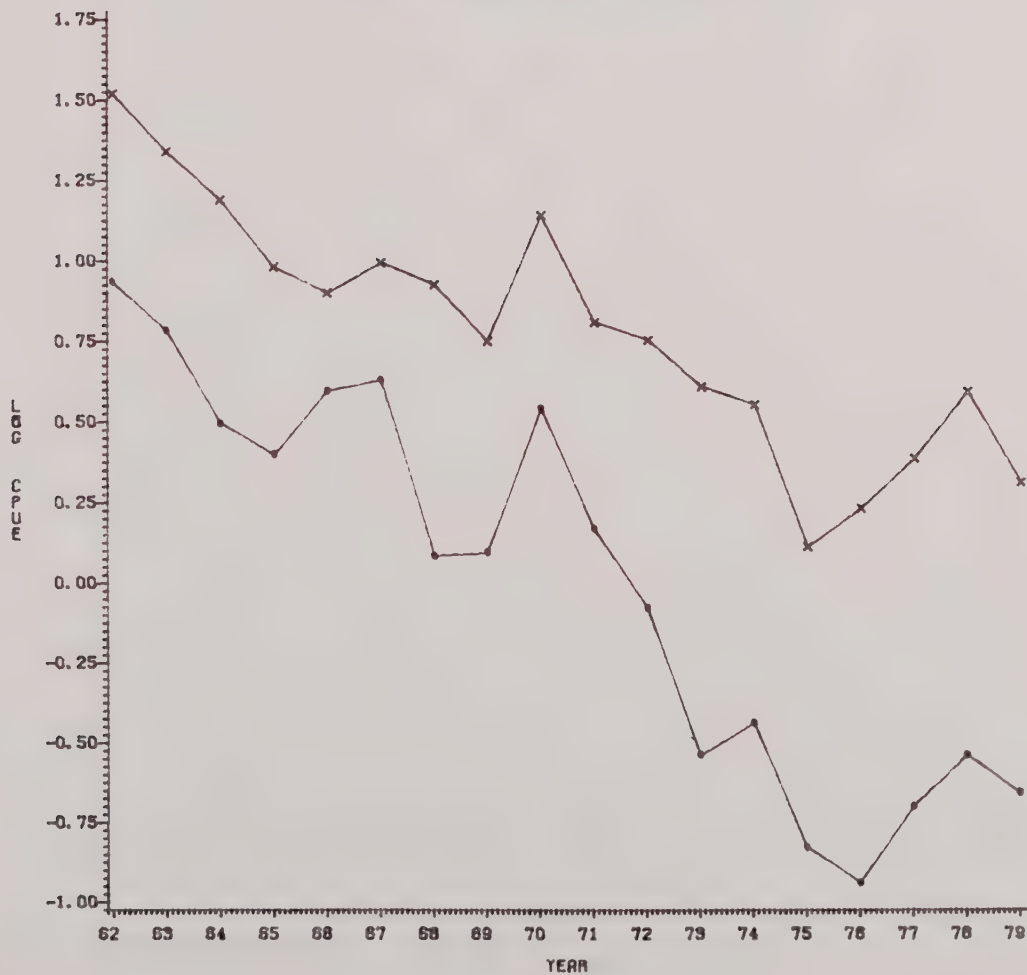


Figure 10.

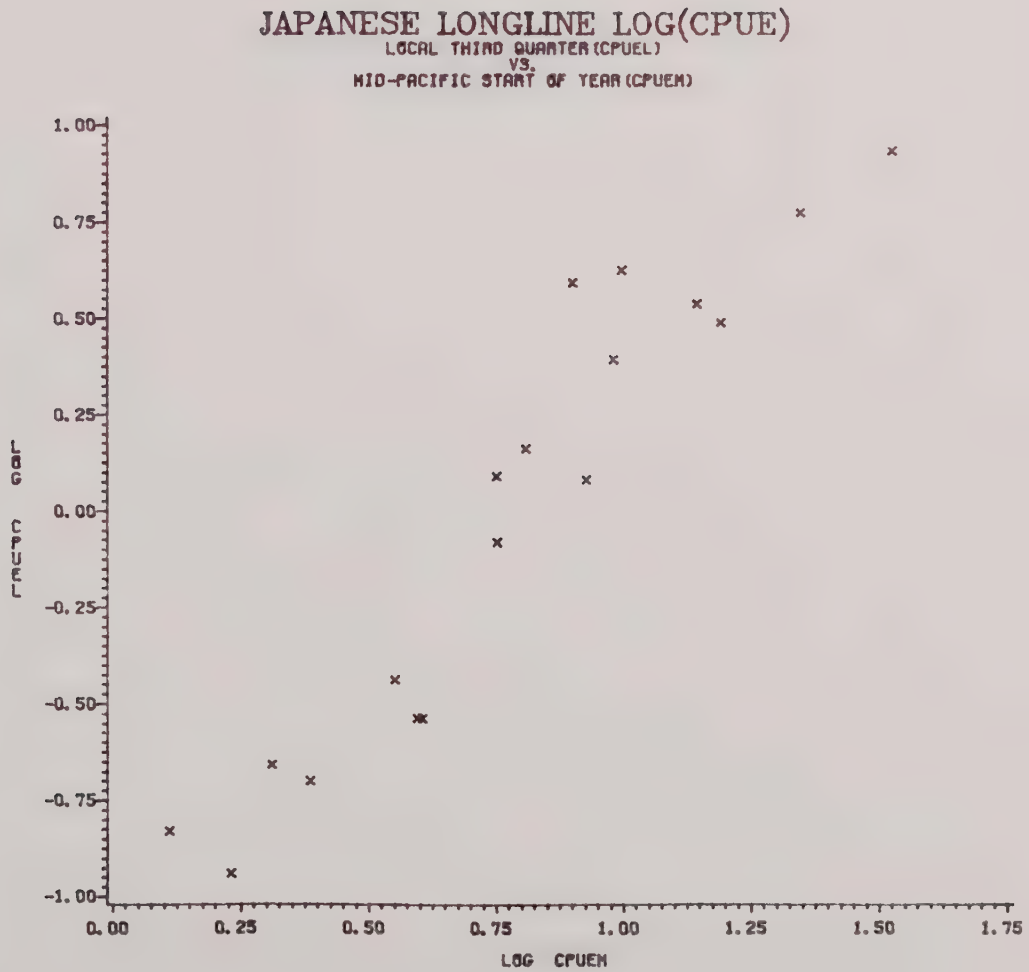


Figure 11.

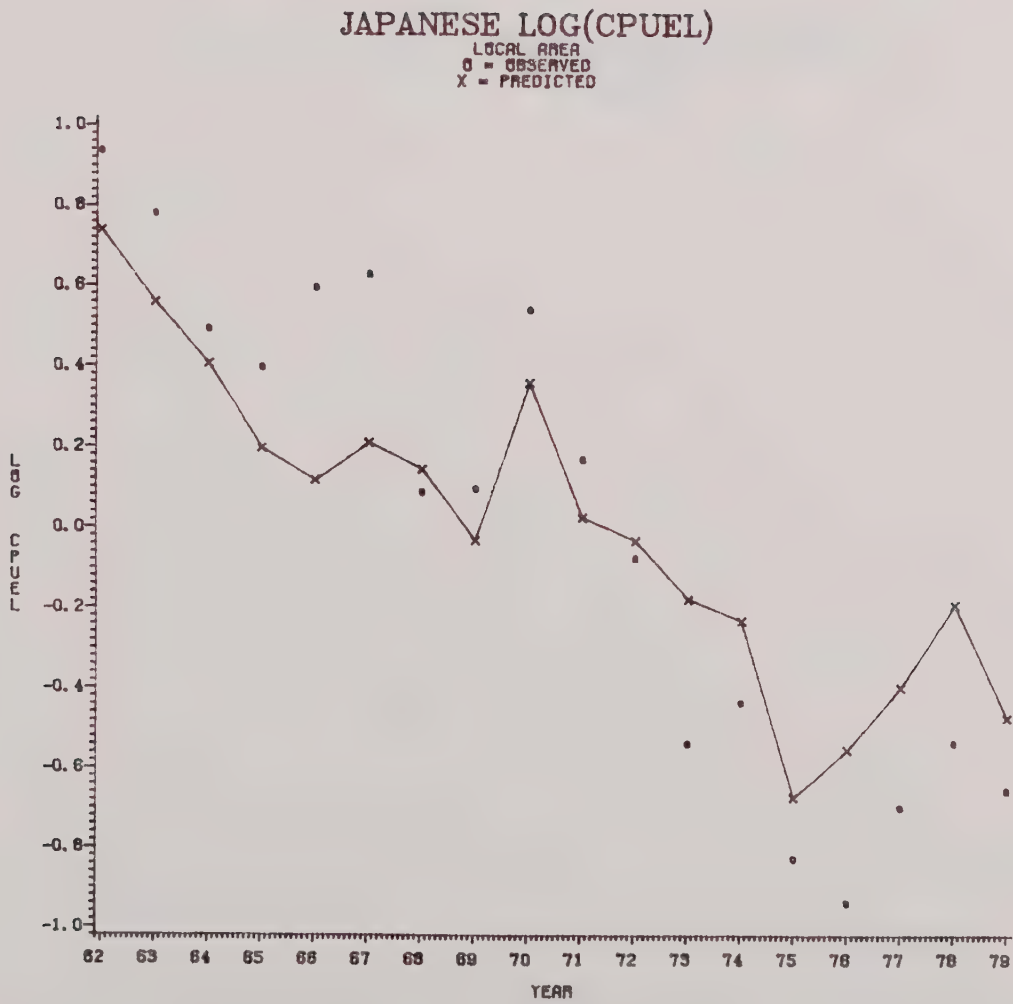


Figure 12.

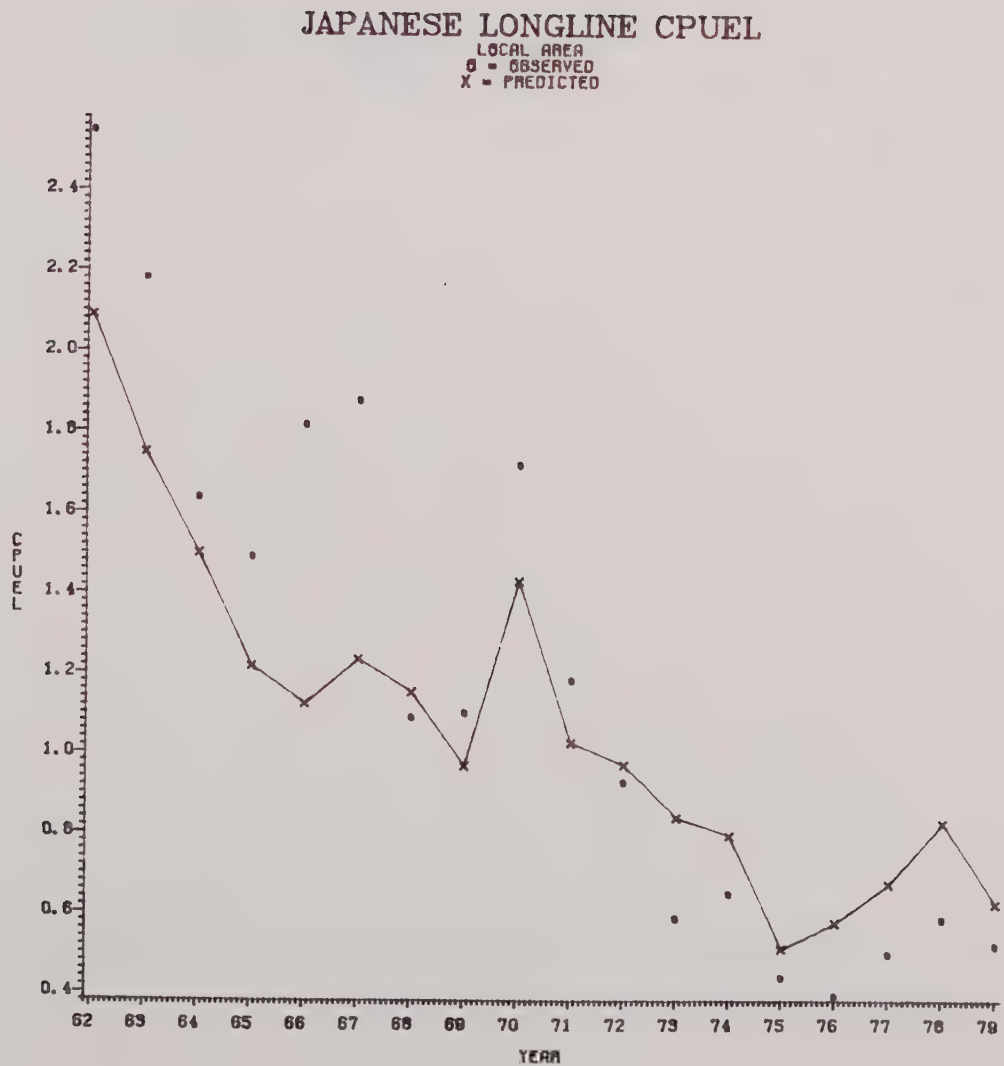


Figure 13.

JAPANESE LONGLINE LOG(CPUEL)

LOCAL AREA
 O = OBSERVED
 X = PREDICTED

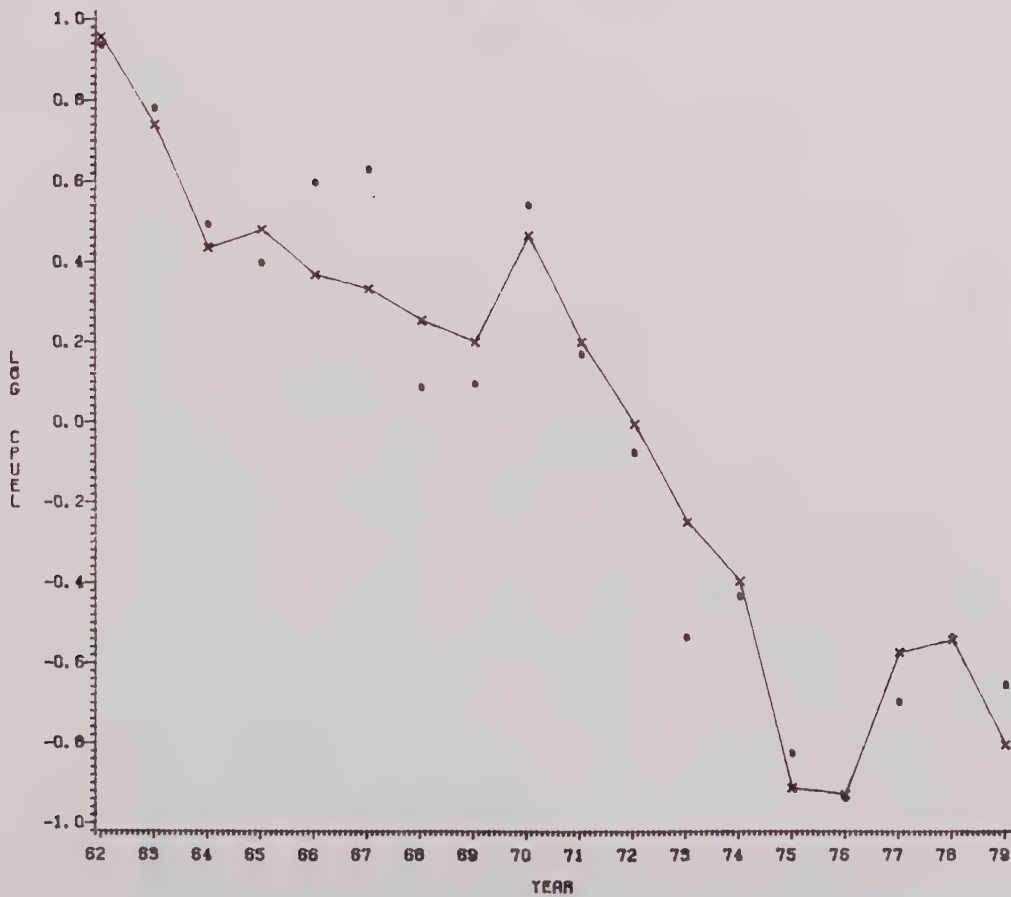


Figure 14.

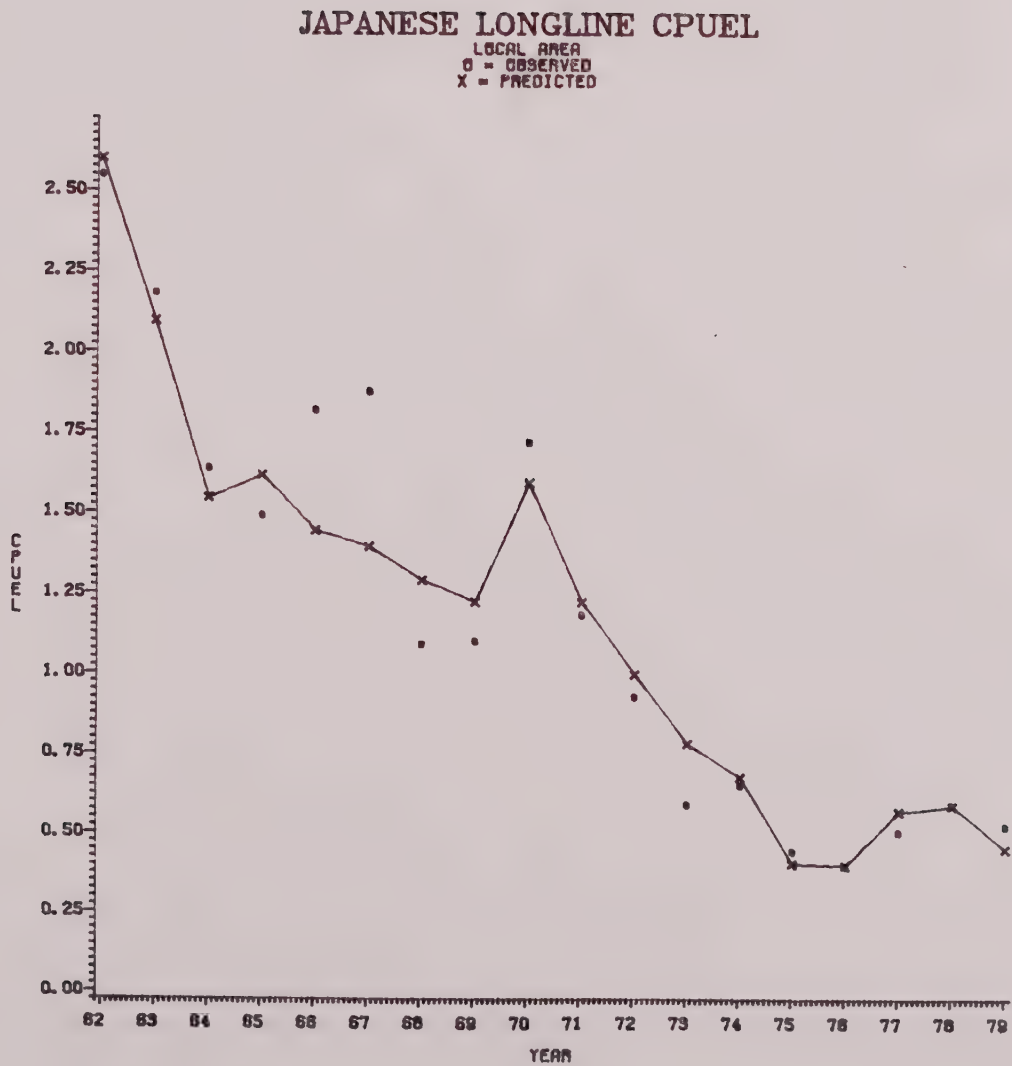


Figure 15.

83-17



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Fisheries Center
Honolulu Laboratory
P. O. Box 3830
Honolulu, Hawaii 96812

**SUBSISTENCE USE OF SEA TURTLES AT PACIFIC ISLANDS
UNDER THE JURISDICTION OF THE UNITED STATES**

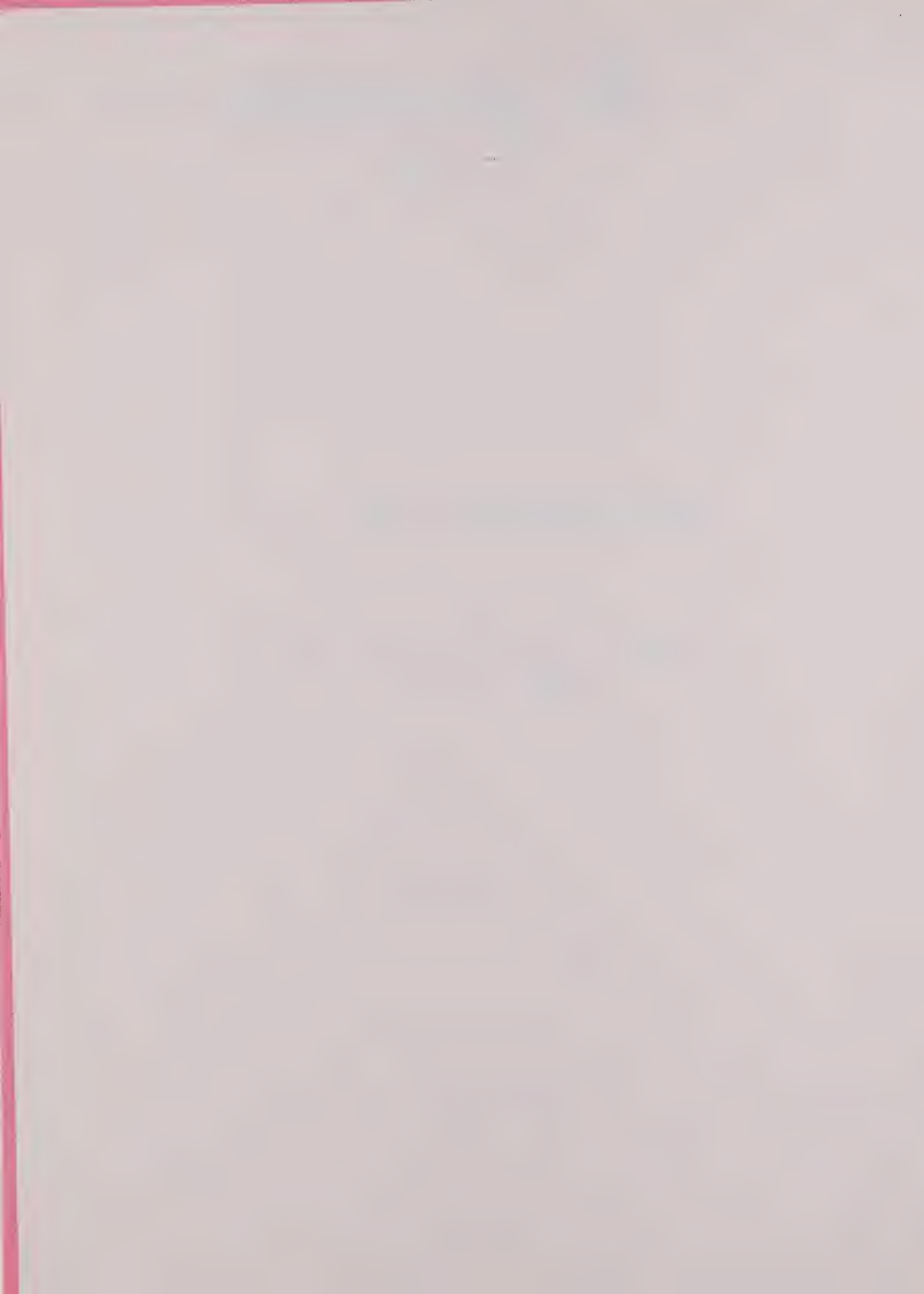
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The islands covered in this report include the State of Hawaii, American Samoa, Guam, and the U.S. Trust Territory of the Pacific Islands. The latter area is composed of the political and geographical districts of Palau, Federated States of Micronesia (Yap, Truk, Ponape, and Kosrae), the Commonwealth of the Northern Mariana Islands, and the Marshall Islands. Other U.S. islands in the Pacific include uninhabited Howland, Baker, Jarvis, and Kingman Reef; as well as Midway, Wake, and Johnston which are inhabited only by military personnel and civilian contract employees. Another U.S. Pacific island, privately owned Palmyra, is currently occupied by a few plantation workers from Kiribati.

Trust Territory

The Trust Territory consists of 2,200 small islands spread over 7.8 million km² of ocean in the western Pacific. The total land area is only 1,800 km². There are approximately 140,000 inhabitants (mostly Micronesians), and 32% of them reside in district centers. The remainder live mostly on remote outer islands.

In 1978 the green, loggerhead, and olive ridley sea turtles were listed under the U.S. Endangered Species Act (ESA). This action had been under review for 4-1/2 years, and culminated in the publication of a Final Environmental Impact Statement by the U.S. Department of Commerce (1978). Protective regulations were promulgated along with the listing in an effort to conserve and restore sea turtle populations to their former levels of abundance. These regulations contained a provision for the continued "subsistence" taking of green turtles for personal use by residents of the Trust Territory, "...if such taking is customary, traditional, and necessary for the sustenance of such resident and his immediate family" (U.S. Department of Commerce 1978). The protective regulations apply to all U.S. states and possessions including those in the Caribbean, but the Trust Territory was the sole area to receive an exemption for subsistence use as defined above. The rationale for this action was that many of the native inhabitants follow a traditional way of life in villages on small remote islands that are limited in natural food resources. Although it is clear that sea turtle populations in the Trust Territory have declined within historical times, the risk to the turtles' survival from subsistence use had to be balanced against the nutritional and cultural needs of the native people. Research reports by Tobin (1952), McCoy (1974, 1982), Pritchard (1977, 1982), and Johannes (1981) seem to support this viewpoint. It should also be noted that the Trust Territory is not owned by the United States, but rather is administered under a United Nations trusteeship scheduled to be terminated in the near future.

American Samoa

At the time of the listing in 1978, no request for a subsistence use exemption was received from American Samoa. American Samoans have many of the advantages of modern technology (i.e., automobiles, electricity, television, telephones, scheduled airlines). Nevertheless, there may still be some legitimate subsistence use of sea turtles, as defined in the regulations. This is likely to be true at Swains Island, a small remote

coral island, inhabited by about 25 people, that is administered as part of American Samoa. Some subsistence use of sea turtles (including hawksbills) may also be justified in certain rural villages on Tutuila and in the Manua Islands of American Samoa. However, based on a series of interviews,¹ there is presently very little interest by Samoans in catching and eating turtles at these locations. In contrast, some of the nationals from other Pacific islands living on Tutuila are reported to regularly hunt turtles.

Guam

During the review process leading to the listing of green turtles under the ESA, the Governor of Guam submitted the following testimony:

"There presently are some minor harvesting of the green sea turtles in Guam waters. We recommend that some harvesting of green sea turtles be allowed but it should be based on accepted management practices such as size limits, limitations on numbers taken, area and time where they may be taken, etc. Also, in this part of the Pacific, any conservation or management regulations imposed must be applicable to all or most of the island areas concerned. The green sea turtles are known to migrate over long distances and conservation measures applied to only a small portion of the thousands of islands in this part of the Pacific will not produce the desired effects of conservation of the species."²

The Governor's recommendation to allow continued taking of green turtles on Guam did not mention that such harvesting is necessary to meet human nutritional needs. Apparently no justification existed to support a subsistence take, as in the Trust Territory. Published studies on marine exploitation and seafood consumption by the people of Guam support this viewpoint, since no mention was made of turtles being of any importance in the diet (Callaghan 1978; Jennison-Nolan 1979).

Before the 1978 ESA listing there were no regulations controlling the taking of green turtles on Guam, although regulatory measures had been under discussion by the local government since at least 1973. When the Endangered Species Act of Guam was passed in 1979, green turtles were given full legal protection at the local government level consistent with Federal regulations (Guam 1979).

¹The interviews were conducted in October 1982 by the author and W. Pedro, Office of Marine Resources, Government of American Samoa.

²Letter dated February 9, 1976 from R. J. Bardallo, Governor of the Territory of Guam to H. M. Hutchings of the National Marine Fisheries Service, NOAA.

State of Hawaii

Correspondence dated July 17 and December 10, 1975 submitted by the Governor of the State of Hawaii during the review process expressed opposition to listing the Hawaiian population of green turtles under the ESA. The reason given was that a State regulation had been promulgated 14 months earlier (in May 1974) that banned commercial turtle fishing, but still permitted the ocean-taking of turtles 36 inches and larger for "home use." The view was expressed that the "total population...can sustain controlled harvest." However, no biological data were submitted to support this position. In contrast, there was evidence to show that Hawaii's green turtles had been overexploited, and, as a result, their numbers and range had been reduced. Before 1974 there were no legal controls on the taking of green turtles in Hawaii. (For a current synoptic review of the Hawaiian green turtle, see Balazs (1980, 1982a, 1982b).)

On April 1, 1976 the Governor submitted a third letter to comment on the Draft Environmental Impact Statement (DEIS) that was circulated for public review at that time. This letter stated that the State of Hawaii was "...cognizant of the 'declining trend' of the Hawaiian marine turtle population..." but had instituted what it thought was "...adequate and effective protection" as a result of the May 1974 regulation. A strong endorsement was given for Alternative 7 listed in the DEIS to "Allow Subsistence Fishing in Areas of Traditional Sea Turtle Fisheries" for Hawaiian green turtles. Since the word "subsistence" was not defined, elaborated upon, or mentioned again in the Governor's letter, it would appear that he equated "traditional subsistence turtle fishing" with the State's precept allowing take for "home use." Home use, however, covered a far broader range of uses, since it was not limited to those persons with a nutritional need to take turtles. Under the State regulation, home use was equivalent to any "non-commercial" take of green turtles. The State regulation therefore allowed the taking of turtles because of food preference and for supplemental but not necessarily essential food for personal use. It also allowed the accidental capture of turtles during other fishing activities and the taking of turtles for sport, recreation, and trophies. After the regulation went into effect, some restaurants continued to serve what was said to be "pre-Act" turtle meat. In one restaurant this reportedly consisted of several thousand pounds stored in a freezer.

Are there people living in the State of Hawaii that could qualify for true subsistence taking of green turtles, as the exemption now applies in the Trust Territory? If there are, they would be very few, constituting only a small fraction of the State's 1 million residents. When the Hawaiian green turtle was listed in 1978 on the basis of the best scientific data available, it was decided that alternate protein food sources were available to replace any turtle meat being used by residents of the State (U.S. Department of Commerce 1978). In the 5 years that have passed since 1978, no subsistence users of green turtles have become known in Hawaii.

An estimation of the number of people having a desire to legally catch turtles in Hawaii can be obtained from the State's official records of the turtles taken for "home use" between May 1974 and September 1978. A total of 84 turtles was reported during this 53-month period. The available records do not show how many fishermen were involved, but it is safe to assume that multiple catches were made by a number of the same people. A liberal estimate would be 35 fishermen, although the actual number is probably less than 20. The number of people taking turtles illegally during this same period was undoubtedly many times greater. The enforcement of marine conservation measures by the State of Hawaii has been a continuing problem. Fishing regulations are often not obeyed, and when violators are caught and prosecuted the fines are too small to be a deterrent (Kiser 1978).

The State of Hawaii is a multiethnic community, and people of part-Hawaiian or Hawaiian ancestry make up about 12% of the population. The people involved in turtle fishing during past years have come from nearly all of the ethnic groups, including Caucasians, Japanese, Chinese, Filipinos, as well as Hawaiians. Sea turtles were clearly a part of ancient Hawaiian culture, entering into such aspects as folklore, personal family gods, sources of material to make fishhooks and other implements, and, for the green turtle (but not the hawksbill), a source of edible meat and fat. There is some historical evidence to show that before 1819 the consumption of turtle was restricted by Hawaiian religion to the ruling nobility, priests, and chiefs (Kalakaua 1888). Although this may not have been true on all islands and under all circumstances, it is clear that before 1819 turtle could not be eaten by women (Malo 1951).

The regulation promulgated by the State in 1974 occurred after 14 months of public review. During this time, public hearings were held on each island to allow ample opportunity for input. Apparently no requests were made at that time asking that special privileges be given for people of Hawaiian ancestry to take turtles. If any requests were received, the State must have rejected them as being unwarranted or inappropriate since such a provision was not part of the final regulation adopted. There are currently no exemptions or special privileges for Hawaiians or other racial groups in any of the fisheries or wildlife laws of the State of Hawaii, and the State administration is not in favor of such exemptions.³

In May 1981 the State's turtle regulation was deleted as a legal precept after being described in a public notice as "obsolete and inactive." However, in March 1982, the green turtle was added to the protected list of wildlife of the State of Hawaii under Chapter 194, where it now receives full legal protection consistent with the federal ESA listing.

³Correspondence dated June 15, 1983 from George R. Ariyoshi, Governor, State of Hawaii to H. K. Cherry.

LITERATURE CITED

Balazs, G. H.

1980. Synopsis of biological data on the green turtle in the Hawaiian Islands. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-7, 141 p.

1982a. Growth rates of immature green turtles in the Hawaiian Archipelago. In K. A. Bjorndal (editor), Biology and conservation of sea turtles, p. 117-125. Smithsonian Inst. Press, Wash., D.C.

1982b. Hawai'i's fishermen help sea turtles. Hawaii Fish. News 7(11):8-9.

Callaghan, P.

1978. Some factors affecting household consumption of seafood and fish products of Guam. Bureau of Planning, Economic Planning Division, Territory of Guam, Tech. Rep. 77-3, 45 p.

Guam, Territory of.

1979. The Endangered Species Act of Guam (P.L. 15-36). Agana, var. pag.

Jennison-Nolan, J.

1979. Guam: Changing patterns of coastal and marine exploitation. Univ. Guam Mar. Lab. Tech. Rep. 59, 51 p.

Johannes, R. E.

1981. Words of the lagoon. Univ. Calif. Press, Berkeley, 245 p.

Kalakaua, D.

1888. The legends and myths of Hawaii. C. L. Webster and Co., N.Y., 530 p.

Kiser, B.

1978. More about poaching. Hawaii Fish. News 2(5):21.

Malo, D.

1951. Hawaiian antiquities. Translated from the Hawaiian by N. B. Emerson, Bishop Museum Press, Honolulu, 278 p.

McCoy, M. A.

1974. Man and turtle in the central Carolines. Micronesica 10:207-221.

1982. Subsistence hunting of turtles in the western Pacific: The Caroline Islands. In K. A. Bjorndal (editor), Biology and conservation of sea turtles, p. 275-280. Smithsonian Inst. Press, Wash., D.C.

Pritchard, P. C. H.

1977. Marine turtles of Micronesia. Chelonia Press, San Francisco, 83 p.

1982. Marine turtles of Micronesia. In K. A. Bjorndal (editor), Biology and conservation of sea turtles, p. 263-274. Smithsonian Inst. Press, Wash., D.C.

Tobin, J. E.

1952. Land tenure in the Marshall Islands. Atoll Res. Bull. 11: 1-36.

U.S. Department of Commerce.

1978. Final Environmental Impact Statement: Listing and protecting the green sea turtle (Chelonia mydas), loggerhead sea turtle (Caretta caretta), and Pacific ridley sea turtle (Lepidochelys olivacea) under the Endangered Species Act of 1973. U.S. Dep. Commer., Wash. D.C., 144 p.





U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Fisheries Center
Honolulu Laboratory
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SEAMOUNT FISHERY, FOREIGN VESSEL OBSERVER REPORT

KITAKAMI MARU (JUNE 9-JULY 21, 1983)

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National Marine Fisheries Service
Southwest Fisheries Center
Honolulu, Hawaii

Nathaniel T. Shippen
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September 1983

1

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On May 16, 1983 the National Marine Fisheries Service (NMFS), Southwest Fisheries Center Honolulu Laboratory (HL) was notified by Nippon Suisan Kaisha, Ltd. of Japan that one of the company's trawlers intended to fish within the U.S. Fishery Conservation Zone (FCZ). It was planned that the trawler, Kitakami Maru (Table 1), would begin fishing in the FCZ during the second week of June.

Table 1.--Vessel specifications and personnel, Kitakami Maru.

Vessel statistics

Radio call sign:	JMLB
Permit number:	JA-83-0321-A
Length:	56.62 m
Gross tonnage:	549.86
Net tonnage:	215.92
Width:	9.2 m
Draft:	3.8 m
Engine type:	Diesel
Horsepower:	1500
Hull number:	100765
Registration number:	F01-132
Company-owner:	Nippon Suisan Kaisha, Ltd.
Vessel type:	Independent stern trawler
Year commissioned:	1966
Home port:	Tobata, Kita-Kyushu, Japan

Personnel

Captain:	Kaname Taketsugu
Number of officers:	8
Number of crew:	19
Processing:	15
Total ship complement:	27
Experience in seamount fishery:	None

As a member of the NMFS HL Foreign Fishing Vessel Observer Program, I was assigned to monitor the Kitakami Maru's fishing operations in the FCZ. I boarded the Kitakami Maru on June 9 at Midway Island. The ship began fishing at the Hancock Seamounts on June 10 and operated there until July 7. It then left the FCZ to fish seamounts to the northwest. On July 13 the Kitakami Maru reentered the FCZ and resumed fishing at Hancock. The ship left the FCZ again on July 15, fishing on seamounts outside the FCZ until July 21. We then met a cargo ship, the Bering Maru, which was carrying observer Alan Everson out from Japan. Everson replaced me as observer aboard the Kitakami Maru. I was transferred to the cargo ship and disembarked at Dutch Harbor, Alaska on July 28.

Compliance

The Kitakami Maru's officers estimated the size of the catch by back-calculating from the weight of finished product. In my opinion, this caused them to underestimate the catch of some species. Small alfoncins and other fish were usually discarded without being weighed. My estimates of both the catch weight percentages of these fish and of total catch were higher than those of the ship.

The Kitakami Maru was boarded by a party from the U.S. Coast Guard cutter Jarvis on July 6. Details may be obtained from U.S. Coast Guard District 14 or the Western Pacific Program Office of the NMFS Southwest Region.

FISHING ACTIVITIES

Trawl Operations

The Kitakami Maru made 104 trawl hauls at Northwest Hancock Seamount (lat. 30°16'-17'N, long. 178°42'-43'E). The average trawling time per haul was 99 min. The ship made 49 hauls at Southeast Hancock Seamount (lat. 29°47'-49'N, long. 179°03'-05'E). The average trawling time per haul at this location was 111 min. Two hauls were made at K-Bank (lat. 29°42'N, long. 179°20' E). The average trawling time per haul was 20 min. The trawl gear dimensions are given in Figure 1. Data on catch per unit of effort by area and species are given in Table 2.

Overall Catch

Out of a total of 151.665 metric tons (MT) caught at the Hancock Seamounts during June 10-July 15, 133.032 MT (87.7%) were armorhead, 9.927 MT (6.6%) were alfoncin, and 8.706 MT (5.7%) were other species (Table 3).

Shipboard Processing of Catch

The catch was processed into headed and gutted frozen fish, and frozen ovaries. The Kitakami Maru had no fishmeal or fish oil plants. All fish or parts of fish that were unsuitable for freezing (inedible species, heads, viscera, small or badly damaged fish) were discarded.

As mentioned earlier, the ship estimated total catch by applying recovery ratios to the weight of finished product. I was not able to discover the exact figures being used. They should, however, be similar to those recorded in previous observer cruises.

Trawl Doors: Shape Rectangular
 Type Steel
 Dimensions 1.84 m. x 2.76 m.
 Weight 1,758 kg.

Dandyline Length 130 m.

Floats: Number 23
 Size 36 cm. diameter
 Material Plastic
 Shape Spherical

Bobbings: Number 23
 Size 53 cm. diameter
 Material 12 steel, 9 rubber
 Shape Spherical

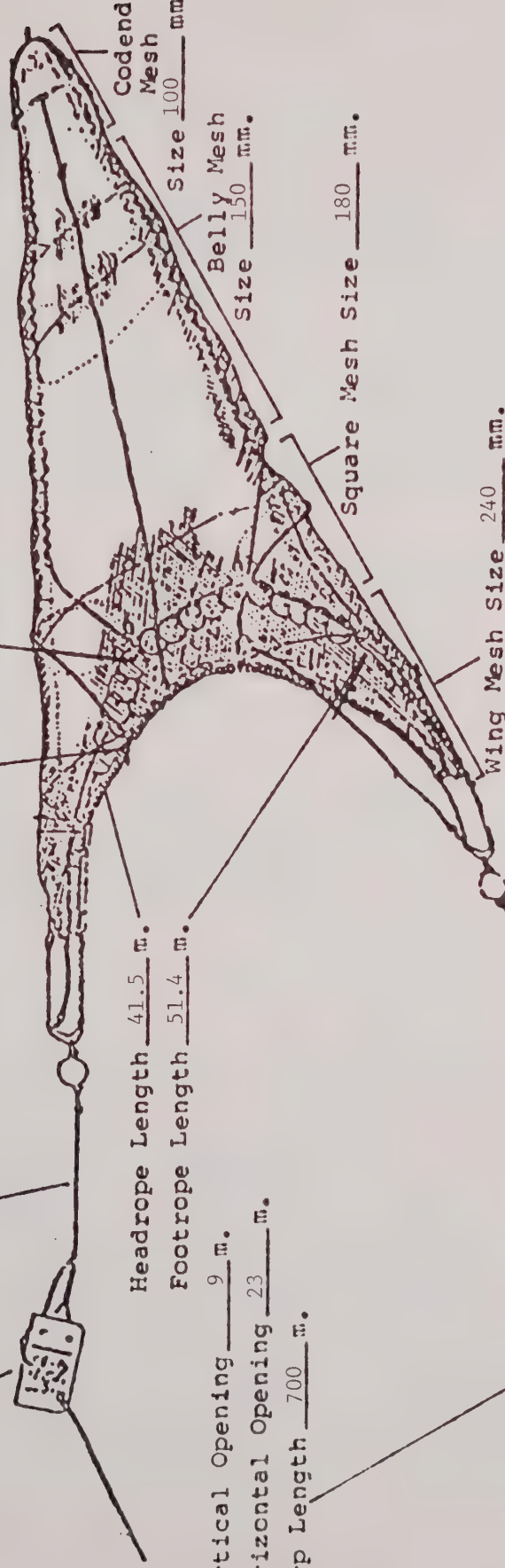
Headrope Length 41.5 m.

Footrope Length 51.4 m.

Vertical Opening 9 m.

Horizontal Opening 23 m.

Warp Length 700 m.



Fish Finder:
 Name Kijodenki
 Model Number Wide size
 Frequency 24,75,200 Hz.
 Paper Type Wet xx Dry
 Speed of Advance 3 ft./min.

Fish Finder:
 Name Japan Radio Corp.
 Model Number NJA-330
 Frequency 28,75,200 Hz.
 Paper Type Wet xx Dry
 Speed of Advance 3 ft./min.

Net Recorder:
 Name Furuno
 Model Number FNR 100
 Frequency 50 Hz. (to ship)
180 Hz. (to bottom)

Figure 1.--Net dimensions and characteristics.

Table 2.--Catch per unit of effort by area and species.

	Northwest Hancock Seamount	Southeast Hancock Seamount	K-Bank
No. hauls	104	49	2
Total minutes ¹ (trawl in water)	10,318	5,460	40
Armorhead			
Total catch (kg)	99,607	33,415	10
Kilogram/minute	9.65	6.12	0.25
Alfonsin			
Total catch (kg)	8,582	1,320	25
Kilogram/minute	0.83	0.24	0.63
Other species			
Total catch (kg)	4,401	4,290	15
Kilogram/minute	0.43	0.79	0.37
All species			
Total catch (kg)	112,590	39,025	50
Kilogram/minute	10.91	7.15	1.25

¹The recorded trawl times include periods when the ship was turning and not over the seamount.

Table 3.--Trawl catch by species and area (in metric tons).

	Northwest Hancock Seamount	Southeast Hancock Seamount	K-Bank	Total
Armorhead	99.607	33.415	0.010	133.032
Alfonsin	8.582	1.320	0.025	9.927
Others	4.401	4.290	0.015	8.706
	-----	-----	-----	-----
Total	112.590	39.025	0.050	151.665

BIOLOGICAL OBSERVATIONS

Target Species

1. Armorhead, Pentaceros richardsoni (Species code: 080)
(Japanese name: Kusakari tsubodai) (Table 4)

Biological sampling of armorhead was done at Northwest and Southeast Hancock Seamounts. I collected data on fork length, weight, sex, and female sexual maturity. In collecting these data I separated the armorhead into three body types: fat, lean, and intermediate (= medium). This division was based on color, the amount of fat on the dorsal side, and the general body shape. The causes of the variation in body type are unknown. I saw many more of the "fat" type and fewer "leans" than I had in previous cruises.

Table 4.--Observations on armorhead, Pentaceros richardsoni.

Body type	Fat	Lean	Medium	Total
Northwest Hancock Seamount				
Percent of sample	6.9	1.4	91.7	100
Number measured and weighed	56	11	741	808
Length range (mm)	296-336	267-309	201-375	201-375
Average length (mm)	315	289	307	307
Average weight (kg)	0.72	0.36	0.49	0.51
Number sexed	56	11	736	803
Number (%) males	35(62.5%)	11(100%)	412(56.0%)	458(57.0%)
Number (%) females	21(37.5%)	0(0%)	324(44.0%)	345(43.0%)
No.(%) imm. females	0(0.0%)		12(3.7%)	12(3.5%)
No.(%) dev. females	21(100%)		293(90.4%)	314(91.0%)
No.(%) ripe females	0(0.0%)		18(5.6%)	18(5.2%)
No.(%) spent females	0(0.0%)		1(0.3%)	1(0.3%)
Southeast Hancock Seamount				
Percent of sample	3.4	0.3	96.3	100
Number measured, weighed, and sexed	13	1	365	379
Length range (mm)	213-327	268	256-330	213-330
Average length (mm)	307	268	305	305
Average weight (kg)	0.70	0.25	0.45	0.46
Number (%) males	8(61.5%)	1(100%)	205(56.2%)	214(56.5%)
Number (%) females	5(38.5%)	0(0%)	160(43.8%)	165(43.5%)
No.(%) dev. females	5(100%)		158(99.4%)	163(99.4%)
No.(%) ripe females	0(0%)		1(0.6%)	1(0.6%)

2. Alfonsin, Beryx splendens (Species code: 081)
(Japanese name: Kinmedai) (Table 5)

Biological sampling of alfonsin was done at Northwest and Southeast Hancock Seamounts. I collected data on fork length, weight, sex, and female sexual maturity. Most of the alfonsin sampled were small, less than 20 cm. Many of these small fish could not be sexed.

Table 5.--Observations on alfonsin, Beryx splendens.

	Northwest Hancock Seamount	Southeast Hancock Seamount
Number measured and weighed	708	212
Length range (mm)	141-383	149-354
Average length (mm)	179	201
Average weight (kg)	0.16	0.23
Number sexed	173	129
Number (%) males	87(50.3%)	59(45.7%)
Number (%) females	86(49.7%)	70(54.3%)
No.(%) imm. females	44(51.2%)	11(15.7%)
No.(%) dev. females	35(40.7%)	53(75.7%)
No.(%) ripe females	7(8.1%)	6(8.6%)

ITINERARY

June	9	-Departed Honolulu Arrived Midway Embarked <u>Kitakami Maru</u>
	10	-Arrived Hancock; began sampling
July	7	-Departed FCZ; sampling ended
	12	-Reentered FCZ; sampling resumed
	15	-Departed FCZ; sampling ended
	21	-Transferred to cargo ship
	28	-Disembarked at Dutch Harbor, Alaska -Departed Dutch Harbor -Arrived Anchorage -Departed Anchorage
	29	-Arrived Honolulu

RECORDS

The following records were kept:

Scientists log
Daily trawl haul form
Species composition from basket samples
Size-frequency log

OBSERVER: Nathaniel T. Shippen
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96812

SOUTHWEST FISHERIES CENTER

HONOLULU, HI 96812

P.O. BOX 3830

September 1983

HONOLULU LABORATORY

NATIONAL MARINE FISHERIES SERVICE

PORPOISE / FISHERIES INTERACTIONS WITHIN THE HAWAIIAN ISLANDS

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Not for Publication

ADMINISTRATIVE REPORT H-83-19C

PREFACE

This report was prepared under contract (83-ABA-00253) by Barbara A. Kuljis. The main objectives of the contract were to determine the distribution, frequency, and type of dolphin/fishery interactions occurring around the main Hawaiian Islands. A survey of Hawaiian fishermen was performed during October and November 1982, to assess this problem. Since this report was prepared under contract, the statements, findings, and conclusions herein are those of the contractor and do not necessarily reflect the view of the National Marine Fisheries Service.

William G. Gilmartin
Leader, Marine Mammals and
Endangered Species Program

September 30, 1983

PROBLEM STATEMENT

The National Marine Fisheries Service Southwest Center, Honolulu Laboratory has recently become cognizant of the increasing adverse impact of porpoise/fishery interactions on the Hawaiian fishing industry. Generally, the overriding complaint of the Hawaiian fishing community concerns the removal of commercially valuable bait and catch from fishing gear by dolphins in a variety of fishing situations. This is not an isolated problem, it occurs in a number of locations including the west and east coasts of the United States as well as in Australia and involves both sea lions and porpoise. The first step in developing a method to ameliorate the situation is to determine the extent and type of interactions. Long term studies directed toward this goal have been or are being conducted on the west coast of the U.S. (Miller 1981, Demaster, 1982), but to date little work has been done in the Hawaiian Islands to ascertain the scope of the problem.

BACKGROUND

In the past decade a number of field trips within the Hawaiian Islands have been conducted by the National Marine Fisheries Service in order to document the problem. These included three trips to the Kona coast of the island of Hawaii and two trips to the Waianae coast of the island of Oahu. These field observations revealed the following; live bait used by trollers were taken by Pacific bottlenose dolphins

(Tursiops gilli); bottom fish caught on handlines were removed from the hooks by the Pacific bottlenose (Iversen 1975); opelu (Decapterus macarellus) caught on handlines at night were taken by a species tentatively identified as the bottlenose dolphin (Peiterson 1982); opelu used as bait on longlines were removed by the rough toothed dolphin (Steno bredanensis) (Naughton 1981). While these facts are critical to begin to understand this fishery problem, the distribution and frequency of these interactions throughout the Hawaiian fishing area has not been fully determined.

There now exists a clear and present need for basic information concerning the various factors which comprise the porpoise/fishery interactions. This report summarizes information recently gathered from fishermen throughout the Hawaiian islands, which will help to define the problem.

OBJECTIVES

The objective of the present study was to survey the Hawaiian fishing community in order to assess the impact of the porpoise/fishery interactions as they relate to the following:

- 1) Geographical distribution: Since the Hawaiian fishery is comprised of a number of islands, some with different species and quantities of cetaceans, is there any one area that is suffering more than another?
- 2) Fisheries most affected: Is one type of fishery affected more than another ?

- 3) Species of animal involved: Of the variety of cetaceans inhabiting Hawaiian waters, which species are impacting the Hawaiian Fisheries?
- 4) Incident Summary: Via what behavioral methods are various species of porpoise carrying out the act of removing bait/catch?
- 5) Seasonal and annual fluctuation: Has there been a marked increase or decrease in the number of interactions during the past decade, and is there any cyclic variation within an annual period?
- 6) Economic impact: What effect do these interactions have on the economics of the Hawaiian fishery?
- 7) Methods used to discourage the interactions: What approaches have local fishermen used to dissuade porpoise from removing bait/catch and how successful have they been?

APPROACH

Because of the reported magnitude and diversity of the fishery interactions, and the distribution of local fishermen within the fishery, personal and telephone interviews of fishermen were used as the most efficient means to obtain the required information within the short time frame of this contract. In order to be consistent a list of questions were compiled and used to conduct the interviews. The list was generated to cover all of the critical parameters involved in this fishery problem. A list of registered commercial fishermen was obtained from the National Marine Fisheries Service, Southwest Center's, Honolulu Laboratory and telephone interviews were selected from those names.

Personal interviews were conducted at local harbors, as well as at fisheries meetings throughout the islands during the contract period. A total of 94 interviews were conducted during the months of October and November of 1982. Thirty eight of these were personal interviews and the remainder were conducted via telephone. This sample represents 6% of Hawaii's registered commercial fishermen. All respondents were guaranteed anonymity in an attempt to eliminate any possible reluctance to respond to specific questions which may have involved illegalities under the current Marine Mammal Protection Act of 1972. Therefore, follow up interviews are not possible nor is querying respondents for more detailed information. An attempt was made to probe areas from which no complaints had been received as well as key areas that had been previously identified as problem areas. It is obvious that this technique did not produce a truly random sampling of Hawaii's registered fishermen, as it only covered those fishermen who attended the fishery meetings or who had listed telephone numbers, or who were present at the docks during the interview periods. These factors should be considered when interpreting the results presented here.

RESULTS

The geographical representation consists of five major fishing areas within the state of Hawaii. They are: 1) the big island of Hawaii, 2) Maui, 3) Kauai, 4) Oahu, 5) Lanai-Molokai. The results presented here are first listed by island, with intra-island areas designated where appropriate, followed by a summary overview of the problem.

HAWAII

This island consists of two major fishing areas, Hilo and Kona. Fishermen who indicated Kona as the area fished utilized the west coast of the island and extended seaward as far as 22 miles off shore to a floating platform known as the OTEC buoy. The Hilo fishermen usually fished the waters off the east to south east coast of the island. The two main fishing types in both areas were handlining and trolling.

In the Hilo area night handlining for ahi (Thunnus albacares) or bottom fishing for opakapaka or pink snapper (Pristipomoides filamentosus) were the predominant fishing types. The major complaint from this area was the loss of bait to porpoise. Few fish were caught when the dolphins were present so most fishermen resorted to pulling up gear for anywhere from 1/2 to 1 1/2 hours and waiting for the porpoise to leave the area. This technique worked; however, the fishermen not only lost time and bait, they also lost any fish that might have been hooked if baits could have been left on lines. The general feeling was that when a boat shut down the porpoise moved to another boat, and worked back and forth. Of the fourteen people interviewed in this area eleven were bothered by porpoise stealing their baits (mainly opelu, Decapterus macarellus). One of the fourteen interviewed lost his catch to porpoise but he had never had bait taken. His catch was generally snapper caught while using cut bait. Two skippers reported losses of both bait and catch to porpoise. Bait/catch thefts were reported to occur from 20 to 50% of the time spent fishing. Cetacean species identification was particularly difficult in these cases because most fishing was done at night. Nine of the fishermen felt that the porpoise interaction problem had increased

over the past four years and had become particularly bothersome in the past two years.

In the Kona area the two major fishing types were: 1) daytime trolling for ahi or marlin (Makaira nigricans) using lures or live bait and, 2) day and night handlining for snappers or ahi. The problem in this area involved the removal of baits before a fish could be caught in the case of trolling and ahi handlining, and detachment of catch from handlines before it could be landed in the case of handliners using cut bait. Of the twenty fishermen interviewed from this area, nine had their bait and catch stolen, three had catch only taken, six had bait only removed and two reported no losses to porpoise. These losses were also reported to occur 20 - 50 % of the time with only one respondent having experienced higher losses. T. gilli were identified as the problem species by inshore fishermen and S. bredanensis were blamed for offshore losses.

MAUI

Of the fifteen fishermen interviewed on Maui thirteen fished off the western shore of Maui in an area surrounded by three smaller islands. Within this four island region the predominant fishing style was bottom fishing with handlines using cut bait or squid to catch snappers. Two of the respondents trolled on the north-west coast of the island and used lures for bait to catch ono (Acanthocybium solandri) and mahi mahi (Coryphaena hippurus). Only one of the 15 people interviewed had ever lost bait or catch to porpoise, and that was only on one occasion. He

had used whole opelu for bait (not his usual bait) and 6-8 porpoise swam by his boat, one of them removed the bait and then moved on. All but one of the other respondents interviewed had seen porpoise while fishing but reported no adverse interactions with them.

KAUAI

Of the twelve fishermen questioned on this island, four had experienced loss of catch to porpoise. One fished off the southeast shore of the island and claimed that he had his ahi stolen by porpoise during the 1960's but no longer had a problem. Two fished in the waters off the south-west coast of the island and had ahi stolen from their lines while trolling but the incident rate was low. Most felt that sharks were a much bigger problem. One bottom fisherman from Hanalei stated that porpoise took akule (Trachurops crumenophthalmus) from his lines while he was bottom fishing, but the problem was not severe and occurred less frequently now than it did in the early 70's. All other fishermen queried had not experienced loss of bait/catch to porpoise but had seen groups of porpoise while fishing and felt they hampered fishing efforts by scaring the fish. No one interviewed was able to give a detailed description of the physical characteristics of the animals so species identification was not possible.

OAHU

Twenty-seven fishermen were interviewed on this island. Ten fished off the west coast of the island in the Waianae area. The remaining seventeen represented the following areas: five from the south shore,

four from the south-east shore, seven from the east shore and one from the north shore. No incidents of bait or catch theft by porpoise were reported from the southern or eastern shores of the island. The north shore respondent claimed to be bothered occasionally by porpoise removing his catch (opelu) . He said the problem was sporadic and not serious.

All ten of the fishermen from the Waianae area had experienced loss of baits and catch to porpoise. All who took the time to respond were handline fishermen. They all fished for opelu and some bottom fished for uku (Aprion virescens) and onaga (Etelis coruscans).

All the respondents from the Waianae area gave the same general description of the interactions. Six to eight porpoise followed the boats out and when lines were baited and placed in the water, a large animal, often accompanied by a smaller animal would move in and clean the hook. When the catch was stolen the animals waited until the hooked fish was near the surface and then pulled it off the line. The fishermen claimed the larger animals were so experienced that they did not damage gear, however the smaller ones broke the lines. All respondents commented on the possibility of the larger animals having been trained as they had seen them tail walk and leap around the boats. It is likely that the interactions in this area were limited to a small group of animals, as the fishermen felt they had seen the same animals over and over. The lowest estimate of the amount of bait/catch lost to porpoise in this area was 33%. Most respondents claimed to lose 75 to 80% of their catch on a regular basis. Most of the Waianae fishermen reported that they pulled up their lines and moved to another location when porpoise were around, in an effort to minimize their losses. One fisherman had tried chili pepper in

his baits with no success, and a few others admitted they had tried shooting the animals. None of these solutions had worked, and the fishermen stated that they had lost more fish in 1982 than ever before. Four of those interviewed claimed that they were on the verge of going out of business. Removing or killing the offending animals were the two solutions suggested by the fishermen to likely be the most effective method of dealing with the problem.

MOLOKAI-LANAI

Six interviews were conducted on these islands, three on Molokai and three on Lanai. Five of those interviewed trolled for ahi or mahi mahi and used lures or cut bait. One was a bottom fisher who used cut bait or squid to catch snapper. Although they all stated that they had seen porpoise while fishing none had experienced any losses to them.

OVERVIEW

Geographical extent- The west, east and southern coastline of the island of Hawaii and the north west coast of the island of Oahu are the major areas currently being impacted by this fishery problem. The southeast shore of the island of Kauai has to date experienced only minor degradation, but the potential is there for further losses. The fisheries of Molokai, Lanai and Maui are not currently experiencing any adverse porpoise fishery difficulties.

Fisheries most affected - The night handline fisheries for ahi, opelu and bottom fish are all affected greatly by porpoise. Daytime ahi and bottom fishermen are also seriously impacted, as are the live bait trollers.

Species involved - The descriptions of the animals involved in harassing night handline fishermen on both the big island and on Oahu indicate that the offenders are Pacific bottlenose dolphins, T. gilli. No clear description of the animals involved off of Kauai could be obtained, therefore no identification could be made. Ahi, bottom, and day time trolling fishermen of the Kona coast near the OTEC buoy are losing fish to the rough toothed dolphin, S. bredanensis.

Incident summary - Night handline fishermen off the eastern and southern shores of the big island of Hawaii claimed the porpoise stationed themselves 5 to 10 fathoms below their boats and ate whatever bait was put in the water, which was generally opelu. They felt that the lights used while fishing attracted the porpoise groups, which ranged in number from possibly 12 in the group off Hilo to only 6-8 off Waianae. Both areas reported that usually only one or two animals at a time fed off their lines. The bottom fishermen from Kona and Waianae said the porpoise waited until the catch was brought close to the surface before pulling it off the hook. Waianae fishermen claimed that they saw the same animals all the time and could identify individual propoises. At the OTEC buoy fish were taken at depths as well as close to the surface. As many as 30 animals were stated to be seen in the waters around the buoy but again only a few at a time harassed an individual boat. The reports from this area indicated that the porpoise moved from boat to boat as fish were hooked. Trollers from Kona stated that one animal would act as a

"decoy" around the boat while another animal moved in and removed fish from their lines.

Seasonal and annual fluctuation - All the areas surveyed, that reported problems with porpoise, claimed that when the fishing was good the porpoise were there. Two fishermen from Hilo and three from Kona felt that their losses were higher during the summer months. Half of those interviewed on the island of Hawaii stated that porpoise interactions had increased over the past two years. One respondent from this area had experienced fewer losses in 1982 than in past years. He had started using fast retrieve reels. All the respondents from the Waianae area felt there was no seasonal fluctuation associated with their losses; however their losses had increased on an annual basis over the past two years.

Economic impact - The average number of fishing days per month was reported to be 15 on the island of Hawaii with a range in catch from 600 to 3000 lbs and bait costs of from \$1 - 2.25/lb. The Waianae fishermen averaged 14 fishing days a month with a catch range from 100 to 300 lbs. Bait costs in this area were reported from \$.70 - 2.50/lb. With an average loss rate of 20 - 50% per trip on Hawaii and 75 - 80% on Oahu these fisheries are being seriously impacted by porpoise.

Methods used to discourage the interactions - The most common method reported was removal of lines from the water and either waiting for the porpoise to move on, or moving to a new location. Some departed the area and went home. Other methods tried were: shooting, poisoned bait, chili pepper in bait, switching from live bait to lures, wire wrapped around the tail of baits, welding rod or copper wire inserted along the back bone

of bait, loud noises, light sticks and fast retrieve reels. Some of these methods were reported to temporarily deter the animals, however, to date none of them have worked for long.

CONCLUSIONS

1. Opelu appear to be one of the target fish being stolen as catch and bait, on Oahu and as bait on Hawaii. Small ahi and snappers also ranked high.
2. Squid, cut bait and fish over 50 lbs were generally not removed from lines.
3. At present only two major fishing areas within the Hawaiian islands are being seriously impacted by the porpoise/ fishery interaction problem. These areas are: the waters surrounding the island of Hawaii and the the waters off the west coast of the island of Oahu (Waianae).
4. Handlining for bottom fish or ahi and live bait trolling are the two fisheries most affected.
5. Within the affected areas, porpoise fishery interactions have increased greatly in the past two years.
6. Losses are adversely affecting the economics of the Hawaiian fisheries, however, the actual dollar amounts vary among fishermen.
7. No method has yet been tried which decreases interactions for an extended period of time.

8. The following should be considered in any control efforts: Opelu appears to be one of the key species of fish involved in the porpoise fishery interactions. Chemical or combination acoustic/chemical control methods utilizing opelu might be helpful in ameliorating this fishery problem. The Waianae fishing area would be an excellent location in which to conduct field trials using the above mentioned techniques. If field trials are conducted an effort should be made to identify individual animals. Any control methods tested should be carefully documented and field trials should be supervised by the National Marine Fisheries Service. Development of alternate fishing techniques may also be an appropriate course of action.

ACKNOWLEDGEMENTS

I would like to thank all of Hawaii's fishermen who took the time to respond to all the questions asked of them. Their patience and cooperation was appreciated.

I am grateful to Mark Suiso, Pete Hendricks, Gayle Ishimoto and Howard Takata of the University of Hawaii's Sea Grant Extension Service for the information they provided me, and for their assistance in contacting fishermen throughout the islands.

I would also like to express my appreciation to the National Marine Fisheries Service Southwest Laboratory for their support and cooperation.

REFERENCES

- DeMaster, D. P. , D.J. Miller, D. Goodman, R. Delong and B. Stewart.
1982 Assessment of California Sea Lion - Fishery Interaction.
Proceed. 47 No. American Wildlife and Natural Resources Conference,
Wildlife Management Institute, Washington, D.C.
- Iversen, R. T. B. 1975 Trip report, Marine Mammals, Hawaii Island
- Miller, D. J. 1981 Marine Mammal Fisheries Interaction Study.
Annual Report for period of July 1979 to June 1980
- Naughton, J.J. 1981 Trip report, Porpoise - Fisheries Interaction
Kona, Hawaii.
- Peiterson, G. 1982 Trip report, Porpoise Fisheries Interaction
Waianae Coast.

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September 1983

HONOLULU LABORATORY

NATIONAL MARINE FISHERIES SERVICE

A FISHERY DATA COLLECTION SYSTEM: SAIPAN

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Not for Publication

ADMINISTRATIVE REPORT H-83-20C

PREFACE

This report was prepared under contract (No. 82-ABC-00224) by CIC Research, Inc. of San Diego, California. The objective of the contract was to develop and recommend a statistically sound fisheries data collection system for the Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife. To do this the contractor made an on-site visit to study the historical data and data collection methodologies used by the Division. Survey techniques and expansion algorithms were developed. Since this report was prepared under contract, the statements, findings, conclusions, and recommendations herein are those of the contractor and do not necessarily reflect the view of the National Marine Fisheries Service.

David C. Hamm
Computer Systems Analyst

September 30, 1983



A FISHERY
DATA COLLECTION SYSTEM:
SAIPAN

FINAL REPORT

Prepared for:

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September 1983



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INTRODUCTION

Since 1979, tourism in Saipan has increased by over 25 percent; an estimated 124,000 tourists visited the Island during 1982. The number of annual visitors to Saipan now exceeds eight times the size of the Island's resident population. This level of tourist activity, coupled with recently enacted regulations governing the purchasing of Island-produced commodities, subjects Saipan's fishing grounds to intense pressure. Not only do these fishing areas support an active commercial fleet, but a significant effort from subsistence and recreational fishermen as well.

At issue is determining the consequences that an increasingly significant fishing pressure will have upon the Island's fishing resources. In order to properly address this issue, a body of data describing the fishing activity on the Island must be compiled. The responsibility for collecting fishing data falls on the Commonwealth of the Northern Mariana Islands' (CNMI) Division of Fish and Wildlife (DFW). It is the duty of the DFW to monitor all fishing activity on the Island in the hopes of identifying levels and trends in fishing participation, effort, and catch. To assist the DFW in their data collection role, this project will furnish the Division with the essential elements of a Fishery Data Collection System (FDCS) and indicate the procedures required to implement such a system.

The purpose of the FDCS is to generate a body of quality data on fishing activity on a continuous basis. Specifically, the major elements of the FDCS are as follows:

- Detailed description of FDCS objectives
- Specification of the general design components for the FDCS
- The required sampling designs
- Sampling activity procedures
- Processing methods for the system's data base
- Expansion algorithms and their reliability
- Quality assurance methods
- Presentation of FDCS data and results

In providing the framework for a FDCS, the study will assist the DFW in enacting a data collection program of its own.

The body of this report is divided into three sections: Section I briefly reviews the DFW's data collection activities. This review includes a look at past as well as current data gathering efforts. Section II describes the eight elements of an FDCS. This description involves a discussion of the range and type of activities which must be undertaken in order to satisfy the requirements for that particular element of the FDCS. Finally, Section III presents the recommendations on how to effectively implement the FDCS in Saipan.

This report is directed at Saipan and not the CNMI in general. However, the proposed system can be readily generalized to include the entire CNMI region. Throughout this report

possible alternatives or strategies for the FDOS will be discussed and assessed. The most feasible solution will always be identified. Again, the primary objective of this study is to serve as the cornerstone for the DFW's future data collection efforts.



SECTION I

REVIEW OF DATA COLLECTION ACTIVITIES

INTRODUCTION

Information describing Saipan's fishing activity has only recently been compiled. In fact, the DFW is now in the early stages of collecting fishing data. Primarily, the DFW's efforts have been directed to a single segment of the Island's fishing activity -- the commercial fishery. The DFW believes that 90 percent of the total Island-wide catch can be attributed to the commercial fishermen.

While the DFW's efforts in the field of collecting primary data may be relatively new, a review of these data gathering activities will be of value. The value of reviewing Saipan's past data collection efforts is twofold. First, such a review will assist during the specification stages of the FDCS's structure by reflecting the unique characteristics of the fishery. Second, by studying the data collection activities, previous pitfalls can be avoided when designing the FDCS. Therefore, this review will serve as the first step in developing a reliable and useful body of fishery statistics.

BRIEF HISTORICAL BACKGROUND OF DATA COLLECTION EFFORTS

The history of data collection efforts in Saipan shows a highly segmented and specialized approach to gathering fishing information. Beginning in the late 1970's, the DFW

entered the field of collecting fishing data. From the outset of these early survey efforts, the DFW has attempted to quantify the fishing activity of the offshore commercial fishery. These initial efforts were focused on the commercial fleet by developing vessel inventories. In addition, during this time, spotted effort was directed to obtaining catch information from the fleet. Most of the collection effort involved surveying retail outlets, thus providing information about only a portion of the commercial catch.

Unfortunately, due to a lack of procedural documentation, inconsistent surveying effort, and missing data, the past data collected is only of limited value. However, this information does provide a measure of commercial fleets' size. Basically, the size of the full-time commercial fleet over the past four years has been fairly stable, with only a slight increase. On the other hand, the part-time commercial fleet has grown over 40 percent since 1979. These figures indicate an overall growth in commercial fishing participation which can be attributed to the part-time fishermen.

CURRENT DATA COLLECTION SYSTEM

The DFW is now in the process of implementing a new data collection system. It is the goal of the DFW to establish a complete system which will accurately reflect the entire Island's fishing activity. During these initial developmental stages, the DFW has undertaken an ambitious survey program. However, before discussing the current program, a few

preparatory remarks are needed in order to place the current program in proper perspective.

Saipan is a relatively small island with 40 miles of beach coastline. The population of Saipan is approximately 15,000 residents. The DFW vessel log shows less than 150 fishing vessels and approximately 40 establishments buying local fish products. Together, each of these seemingly disjointed facts reveals a fishing activity level which is not numerically staggering and which may be suited to certain data collection procedures not normally feasible.

The DFW's personnel, primarily responsible for implementing the current system, possess unique and valuable knowledge about Saipan's fishing activity. Not only do these individuals have this knowledge base, but they personally know most of the Island's fishermen. These personal relationships represent a valuable asset to successfully implementing the current system.

Description of the Data Collection System

The DFW has chosen to develop its FDACS in a segmented manner by concentrating on a single type of fishing activity at a time. The focus of the current system is the commercial fishery. This fishing activity is the obvious choice because the bulk of past data collection efforts have been directed to commercial fishing. Essentially, the current system can be described as a census survey of the commercial fleet. The fleet includes full as well as part-time fishermen.

Two survey instruments have been developed and are being used to obtain the desired data. The first instrument is a fishing logbook. A logbook is provided to each fisherman. The fishermen are instructed on how to fill out the log information sheet. A sample information sheet is presented in Figure 1. At the conclusion of each fishing trip the fisherman is asked to fill out an information sheet completely. The DFW collects the information sheets on a monthly basis. Basically, the information collected from the commercial fishermen includes catch data, number of fishermen (participation), time fishing (effort), and fishing gear. The DFW meets regularly with the fishermen to ensure that the logbooks are kept current.

The second survey instrument is directed at another level in the marketing chain of fish -- the fish purchasing establishments. At the present time, the breakdown of these establishments is as follows:

- Hotels - 17%
- Retail Outlets - 40%
- Restaurants - 13%
- Government Programs - 3%
- Mobile Stands - 27%

Division of Fish and Wildlife
Department of Natural Resources
CNMI Government
Fish Landing data (88-309)

Boatname/Number

Fuel Consumed _____ gals. () Gasoline
() Diesel

Number of fishermen on Board _____

Type of fishing:

- () Trolling
() Bottom fishing
() Spear fishing
() Gill Net
() Trap
() Other (Specify)

Catch Report

[illegible]

Each establishment is supplied with a stack of commercial sales data forms. A copy of one of these forms is shown in Figure 2. Each form is to be filled out at the time of a fish purchase. The form primarily solicits catch information concerning the sale. The DFW works closely with these establishments to ensure that the sales information is properly recorded. Every two weeks or so, the DFW collects these forms. The DFW regularly updates the list of fish purchasing establishments and makes sure that all are well supplied with forms.

By providing survey instruments to all known commercial fishermen and fish-purchasing establishments, the DFW is censusing the commercial fishing activity. This data collection effort was begun in late 1982. By the beginning of 1983, the vast majority of fishermen had been given logbooks and all the fish buyers had been furnished with sales data sheets.

From the data compiled by the DFW, the following general information is known about the commercial fishing on the Island. Table 1 shows the breakdown of Saipan's boat population by the fishing activity in which the boats are primarily engaged.

Figure 2

DIVISION OF FISH & WILDLIFE
Department of Natural Resources
CNMI-Government

COMMERCIAL SALES DATA 550

BUYER: _____ DATE: _____

SELLER: _____

SPECIES	No. of Pieces	Price per Pound	Total Weight (lbs.)	Total Value
PELAGIC				
1.. Skipjack Tuna/Katsuo				
2. Yellowfin Tuna/Manguro				
3. Dogtooth/White Tuna				
4. Wahoo/Saowara				
5. Mahi Mahi/Dolphin				
6. Barracuda/Alu				
7. Rainbow Runner/Burri				
8. Marlin				
9. Other				
REEF FISH				
1. Big Eyed Scad/Atulai				
2. Goat fish/Satmonetti				
3. Squirrelfish/Sagamelon				
4. Mullet/Laiguan				
5. Rudderfish/Guili				
6. Rabbitfish/Hiting				
7. Surgeonfish/Hijok, Hugupao				
8. Parrotfish/Laggua				
9. Unicorn/Tataga				
10. Wrasse/Gaddas				
11. Other				
BOTTOM FISH				
1. Snapper/Mafuti				
2. Grouper/Gadao				
3. Onaga				
4. Opakapaka				
5. Gindai				
6. Other				
Lobster/Mahongan				

Table 1
PRIMARY FISHING ACTIVITY OF
SAIPAN'S BOAT POPULATION

<u>Primary Fishing Activity</u>	<u>Percent Participating In Primary Activity</u>
Full-time commercial fishing	23.4%
Part-time commercial fishing	68.8
Recreational fishing	7.1
No fishing	0.7

Source: CIC Research, Inc.
DFW

Ninety-nine percent of the boats in Saipan are used for fishing. The majority of these boats participate in part-time commercial fishing.

The primary fishing method for the commercial fleet is trolling, with spearfishing the most prevalent secondary method. Table 2 shows the distribution of fishing boats by fishing method, both primary and secondary. Principally, there are four fishing methods used: trolling, bottom, spear, and handline. Most of the fishing fleet is able to readily change fishing gear; this is especially true for the part-time fishermen.

Table 2

PERCENT DISTRIBUTION OF FISHING BOATS BY
PRIMARY AND SECONDARY FISHING METHODS

<u>Fishing Method</u>	<u>Percent of Boats</u>	
	<u>Primary Method</u>	<u>Secondary Method</u>
Trolling	79.9%	-0-
Bottom	-0-	13.7%
Spear	11.9	45.3
Handline	7.5	35.2
Other	.7	5.8
	100.0%	100.0%

Source: CIC Research, Inc.
DFW

ASSESSMENT OF DATA COLLECTION ACTIVITIES

To assist the DFW in evaluating its data collection efforts, this concluding segment of Section I assesses the current programs. This assessment looks not only at the operational aspects of the program, but considers the theoretical approach as well. The comments contained in this section are not necessarily presented in order of their importance to the overall data collection program.

Feasibility of Voluntary Fishermen Logbooks

The current survey program rests upon the success of fishermen maintaining logbooks. From a historical perspective, a

voluntary logbook program in the fishing industry seldom yields the desired information. The reason is simple: fishermen fail to complete the logbook information requested. Therefore, the odds appear to be against the DFW making the logbook program workable. However, two factors are in the Division's favor, if they are properly implemented. First, DFW personnel know the fishermen on a personal level. These relationships will undoubtedly assist the DFW in obtaining the logbook information. Second, the number of fishermen on Saipan is small enough to make tracking each fisherman feasible. The DFW should be able to monitor the fishermen on a regular basis. If the DFW spends the necessary time and effort, the likelihood of having a successful voluntary logbook program will be greatly increased.

Census Survey Approach

Another element in the logbook program is the DFW's desire to census the Island's fishermen and fish-buying establishments. Two issues must be considered in this area of the survey program. First, for the census to succeed, each member of the census group must be identified. Therefore, the DFW must update the status of each fisherman and fish buyer on a continuing basis, as well as add any new member to the appropriate group. Also, the future feasibility of a census survey must be reviewed. As the fishing industry in Saipan grows, will it still be practical to census the entire industry? If not, the DFW must consider alternative sampling programs and determine the set of conditions that must exist in order to implement the new scheme.

Survey Instruments

Careful consideration should be given by the DFW to the survey instruments now being used. The DFW must first determine what type of information it desires in its efforts to describe the Island's fishing activity. Usually, fishing data comprises information on catch, effort, and participation. Also, to assist in evaluating this data, information concerning gear used and weather conditions is often collected. The questionnaire should be easily understood by the respondent to ensure that it is properly filled out. In addition, information from fishermen should be sought concerning the questionnaire design. The scope of the questionnaire must also be defined. For example, is the survey instrument to be used for all types of fishing activity (i.e., full-time commercial, part-time commercial, recreational) or is a separate questionnaire required for each group? The DFW must resolve each of these issues before the program can be properly implemented.

Overall Data Collection Strategy

By focusing on only the commercial fishing sector, the DFW is segmenting its data collection efforts. In view of the fact that the DFW has been collecting fishing data for only a short while, this strategy is sound. In building a data collection program, often the entire program is started up at once. This type of start-up process usually leads to numerous problems in all areas and significantly reduces the quality of the data being collected. By implementing the data collection effort in

a step-wise fashion, the likelihood of having a successful program is greatly increased.

Other Activities Involved in Collecting Data

Even though the DFW is targeting the commercial fishery alone, a number of activities must be engaged in to ensure that the desired data is obtained. The entire program must be fully documented in terms of procedures and methods introduced to collect the fishing information. Without proper documentation, future analysis of the data would be severely restricted. Specifically, the DFW must define the following activities:

- Data tabulation methods
- Data processing methods
- Data expansion procedures
- Quality assurance methods
- Document surveying procedures
- Alternative survey strategies
- Presentation of results

Often, little thought is given to the many activities surrounding the actual collection procedures. Failure to consider the activities listed above leads to the collection of a body of numbers with little, if any, value to providing insight into fishing activity. Sections II and III of this report address these issues in detail.

Summary

Basically, the DFW is proceeding with a data collection program which, if implemented properly, should be successful. However, the program will require constant attention, especially during these early stages. The DFW must look at the current program within the context of a completed FDCC -- an outline of which is presented in the next section. The process of collecting meaningful fishery data is based upon structuring a feasible system of data-gathering procedures. The DFW is now beginning that process.



SECTION II

ELEMENTS OF A FISHERY DATA COLLECTION SYSTEM

INTRODUCTION

This section of the report describes the basic elements of an FDACS without addressing the specific needs of the Saipan fishery. In addition, this section outlines the activities that must be undertaken in order to implement such a system. For ease of understanding, this section of the report is written in semi-outline form, identifying those key factors which comprise each element of the FDACS. These elements are:

- description of FDACS objectives
- general design components for the FDACS
- required sampling designs
- sampling activity procedures
- processing of the system's data base
- expansion algorithms and their reliability
- quality assurance methods
- presentation of the FDACS's results

Each of the eight components of the FDACS is presented and discussed in the remainder of this section.

OBJECTIVES OF A FISHERY DATA COLLECTION SYSTEM

Before undertaking a survey investigation, it is essential for the investigator to consider the kinds of things

he/she would like to know. The investigator should determine what the ultimate objective is and be prepared to state it clearly as the research goal. The essence of an FDCS is reflected in its objectives which provide the conceptual framework needed in directing the collection of fishery information. The following factors must be addressed during this initial stage of defining the FDCS:

- Specify research goal.
 - Compose a broad statement concerning the overall purpose of the research. This statement may deal with objectives beyond the results derived by the immediate study.
 - State the overall strategy for the data collections effort.
- Establish working objectives.
 - Break down research goal into a series of small operational objectives. The sum of these objectives is another way of stating the research goal.
 - Determine whether each individual's working objective may require a separate data collection activity.
- Define universe to be observed.
 - Specify what entities are to be observed in obtaining information concerning fishing activity.
 - Provide the statistical framework for future analysis.
- Delineate specific concepts and characteristics to be observed and measured.
 - Identify which characteristics are to be selected from the universe.
- Determine numerical values to be developed.
 - Decide which averages or totals are to be compiled.

- Decide which processes are to be examined.

Each of the above items is to be reviewed within the context of collecting fishing information. Many times the failure of a fishery data gathering effort can be traced to the lack of clearly-defined objectives. Properly stated objectives provide the directional focus for the FDCS.

GENERAL DESIGN COMPONENTS FOR FISHERY DATA COLLECTION SYSTEM

General design components refer to those considerations which must be examined during the formulation of the overall surveying design. In effect, these components act as framing constraints to the FDCS. The set of general design components can be divided into three groups: fishing experience, surveying factors, and surveying effort. While these three groups undoubtedly influence each other, for the purpose of this presentation each group will be outlined separately.

Fishing Experience

Understanding the nature of the fishing experience enhances the likelihood of selecting the proper structure for the FDCS. The fishing experience can be looked at in terms of its human, spatial, and temporal elements. Each of these elements must be considered in regard to the following factors.

- Consider human factors in the fishing experience.
 - Determine what is known about the fisherman participating in the fishing activity.
 - Assess what information is available concerning the fisherman's catch, participation, and effort.

- Classify the fisherman according to the reason for fishing, e.g., commercial, recreational, subsistence.
- Determine what is known about the non-fisherman. This information will assist in developing participation rates. If this information is not readily available, adjustments will be required in the FDCS.
- Identify primary fishing methods: inshore and offshore with respect to gear.
- Develop a fisherman profile built on existing data and knowledge. Once the FDCS becomes operational, this profile may change.
- Consider spatial factor in the fishing experience.
 - Identify locations for fishing activity, both inshore and offshore. The goal is to define the level of fishing effort occurring at a specific location. In the case of the offshore fishery, these locations are boat launching sites.
 - Determine how best to examine these sites, again both inshore and offshore.
 - Account for the entire Island in terms of its fishing activity or lack of it.
- Consider temporal factors in the fishing experience.
 - Select temporal unit of measure, usually a day.
 - Determine how FDCS will cover the entire 24-hour period.
 - Establish means for estimating the fishing activity during the 24-hour day.

Surveying Factors

A number of surveying factors exist which, upon identification, reveal in general terms the surveying procedures to be followed. These factors are as follows:

- Select unit on which determinations are to be made.
 - Determine which items are to be sampled and measured (ultimately, this unit is the fisherman; however, other units, i.e., boats, fishing sites, retail outlets, can provide information useful in the design and effort allocation stages.)
 - Determine advantages and disadvantages associated with each possible unit.
- Review possible surveying or sampling methods.
 - Specify methods: face-to-face interviews, sampler observations, telephone interviews, or mail interviews.
 - Determine the best way of obtaining the desired information.

Surveying Effort

The final design component to be considered deals with surveying effort. Three factors influence surveying effort: costs, variability, and tolerated error. Specifically, the following items must be considered when assessing these three factors.

- Develop preliminary cost information.
 - Review the proposed surveying proposals, and estimate cost figures.
 - Identify the fixed and variable costs from the above calculations.
- Assess variability of key variables to the FDCS.
 - Identify key variables for catch, participation, and effort (this is a statistical or numerical issue).
 - Develop some measure of the variance associated with each of the above variables.

- Identify factors, e.g., fishing gear, which tend to effect the variability of the above three variables.
- Select tolerated error level.
 - Determine the amount of error the FDCCS will tolerate, i.e., 5, 10, 20, 50 percent.
 - Specify reasons for selected error figure. (Error level will be affected by budgetary factors, FDCCS's objectives, uses of the data.)

Together, these three factors will enable actual levels of surveying or sampling effort to be determined. Such figures will be helpful during the sampling design stages.

THE SAMPLING DESIGN

While this element of the system is entitled Sampling Design, in fact it encompasses all designing functions related to the development of the entire FDCCS, whether actual sampling is required or not. Hence, the sampling design specifies what procedures are to be followed in generating the desired data necessary for estimating fishing activity, especially total Island harvest. The determination of these procedures evolves from a selection process which takes into account each factor of the FDCCS previously discussed, as well as the proposed expansion methods to be used. Essentially, the design procedures can be classified as two basic techniques: either statistical survey methods or qualitative inference methods. A statistical survey method refers to those procedures which involve observing fishing activity in a systematic fashion and thus rely primarily upon sound statistical survey theory. Qualitative inference methods, on the other hand, do not rely upon statistical bases, but involve arbitrary observation techniques.

Statistical Survey Methods

- Determine whether or not the observation unit can be surveyed.
 - Define nature of activity each observation unit is involved in, e.g., day inshore fishing (usually, the observation unit is the fisherman).
- Select survey method to be used.
 - Decide between sample and census
- Design survey procedures needed to properly examine the observation unit. (These procedures will obviously vary with each survey program. For the FDOS, the survey procedures center around catch, effort and participation activities.)
 - Determine if the activity to be surveyed can be stratified in some manner.
 - Choose sampling unit for each surveyed activity, e.g., fisherman, boat, fishing site, and so forth.
 - Decide if the survey requires sampling and, if so, determine the number and type of stages and places in the design. (A sampling stage refers to a level of sampling; if a two-stage design is employed, two levels of sampling exist. For example, an offshore design may require sample launch sites to be taken, then a sample of boats within each site. A sampling phase deals with the number of variables to be measured -- one phase for each variable.)
 - Determine sampling effort, i.e., the number of sampling units to be taken at each stage and at each phase. Allocate survey effort.
 - Estimate cost of survey operation.
 - Choose method for selecting sampling units, i.e., probability or judgment.
 - Outline procedures for dealing with "hard-to-get" fishing activities through sampling, e.g., night fishing.
 - Outline methods of making estimates from surveyed data.

Qualitative Inference Methods

- Re-examine fishing activities which cannot be surveyed.
 - Determine why activity cannot be adequately surveyed.
- Identify and select those procedures which will provide information about these activities.
- Describe method for obtaining information about these "hard-to-get" activities, e.g., illegal fishing.
- Calculate costs and effort required to measure activity by qualitative means.
- Outline methods of making estimates from information obtained from the selected procedures.

The sampling design element of the FDCS is the single most important component of the system. This element lays out the entire design for obtaining the desired numerical estimates of fishing activity. Properly designing the system minimizes future problems that always occur in any data collection system.

THE SAMPLING ACTIVITY

This element of the FDCS deals with the actual implementation of the sampling design. Under normal circumstances, a sampling design dealing with fishing activity requires multiple data collection operations. Successfully implementing such a data collection system requires careful planning and involves a number of activities outlined below:

- Formulate sampling design structure into a series of detailed survey procedures.

- Fully describe the sampling design. (This step is an operational effort. It takes, for example, the idea of sampling offshore fishing 30 percent of the time to sampling every other day from 6 a.m. to 5 p.m. at a given site.)
- Design all recording forms.
 - (Examples of recording forms are questionnaires, tally sheets, samplers' log books, survey protocol packets, coding books, and any forms required for conducting the surveys).
 - Use existing forms as a basis for the set of recording forms. (A good rule of thumb is that a form should exist at each stage of the sampling program.)
 - Maintain tally sheets as questionnaires are collected, indicating whether or not the questionnaires are fully or partially completed, edited, etc.
 - Document sampler information gained during the survey activity on the proper forms. (This information will aid in the adjustment process associated with a new survey, as well as ongoing survey efforts.)
 - Keep the information in a sampler's log book, documenting the sampler's daily activities.
 - Develop a survey protocol packet and give one to each sampler. Items in the protocol should, at least, include the following:
 - sampler instruction manual, including a question-by-question discussion of questionnaire administration
 - statement of purpose and background of the study
 - scheduling calendar
 - tide and moon phase calendar
 - special instructions and notes of unique circumstances of which the sampler should be aware.

- map of survey route
- coding sheets
- administrative requirements
- sampler's log book
- Select and train sampler
 - Make sure that each individual involved in the survey procedures thoroughly understands their specific survey responsibilities as well as the program's objectives. (The training process is especially needed for those individuals participating in the qualitative inference methods.)
- Develop controlling procedures for sampler.
 - Adopt methods which allow the sampler's activities to be monitored and evaluated on a continuous basis.

PROCESSING THE SYSTEM'S DATA BASE

In general terms, as the survey work is completed, data processing procedures must be in place to ensure that the final data set is accurate. These data processing procedures commence the moment a questionnaire is brought out of the field.

- Prepare data processing facilities.
 - Set aside the necessary space to meet expected incoming data requirements.
 - Review processing status forms to make sure each processing step is properly set up. (The processing status form defines each of the steps necessary in processing the raw field data into the computerized form of the final data set.)

- Define data processing procedures.
 - Explain in detail each step of the data processing sequence, detailing how, what, when, and by whom that particular step is to be implemented.
- Review data set format designs.
 - Examine the format design and the incoming data to make sure they are compatible.
- Key punch data into computer file..
 - Maintain original questionnaire for at least a year after all activities for that year's FDCS have been completed. (If space is available, hold questionnaires longer.)
 - Maintain necessary back-up files.

The key to this stage of the data collection activity is the existence of clearly-stated procedures for processing the raw field data into the form of the final data set.

EXPANSION ALGORITHMS AND THEIR RELIABILITY

The results of the survey activities provide numerical estimates of surveyed fishing activity only. The goal of the system is to develop estimates of Island-wide fishing activity. Obtaining Island-wide estimates from sampled data requires the use of an expansion mechanism. This expansion mechanism defines the functional relationship between the sample results and the desired Island-wide results. The expansion procedure involves calculating a point variable, usually total catch.

- Describe Island-wide fishing activity in terms of a mathematical equation..

- Write the equation first, in an implicit form, i.e., total catch equals offshore plus inshore catch. (Identify all variables in the equations.)
- Write out the equation next, in an explicit form, actually defining the mathematical relationship between the variables.
- Define the catch, effort, and participation activities through these equations.
- Review results of survey efforts.
 - Identify which survey results can be used to replace variables in the expansion equation.
- Review results of qualitative inference efforts.
 - Identify which qualitative results can be used to replace variables in the expansion equation.
- Review entire expansion equation to insure that all elements of the equation can be numerically estimated.
 - Document how proxy measure was calculated, if additional variable specification is required.
- Compute appropriate variance measure for each expansion equation.
 - Identify variables in equation with non-zero variance.
 - Specify variance calculation for those variables. (The nature of this calculation will be dependent upon the sampling schemes employed in estimating those variables. For example the variance formulated for a simple random sampling scheme and a stratified random scheme are different.)
 - Compute variance measure for the equation as a whole, drawing upon the mathematical properties of a variance (i.e., the variance of a sum of variables or a product of variables has certain functional forms).
- Define reliability measure.

(This measure is usually a statistical confidence interval.)

QUALITY ASSESSMENT METHODS

An essential part of the FDCS is a series of quality assessment (QA) procedures. These procedures act as checks to insure that the data being collected, processed, and manipulated meet the desired quality level. QA procedures can be classified into two groups: internal and external. Internal methods involve sampling procedure checks and data processing checks, while external methods entail comparing estimated results with data from independent sources.

QA -- Internal Methods

- Undertake sampling procedure checks.
 - Direct these efforts to the survey activity element of the system.
 - Review sampler-specific survey results to uncover potential sampler bias.
 - Assess and, if necessary, adjust sampling allocation efforts from a review of new incoming data.
- Undertake data handling checks.
 - Gear these checks to evaluating whether additional error is being introduced into the system.
 - Subsample the data set and compare this sample with the original questionnaire. (If the error rate from the subsample is significantly higher than the desired rate, then the entire data set would have to be rechecked.)

QA -- External Methods

- Compile independent source material.

- Use these sources to develop independent fishing estimates. (Examples of these independent sources include demographic data, other related surveys and reports, e.g., the National Marine Recreational Fishing Survey.)
- Compute independent measure and compare with FDACS estimate. (For example, fishing participation estimates can be compared with population figures to determine if the relative sizes are reasonable.)

Together these QA methods provide the assurance necessary to generate a useful and viable fishery data collection system. Hence, a fundamental part of the FDACS must be a well-defined QA program.

PRESENTATION OF THE FISHERY DATA COLLECTION SYSTEM

Careful consideration must be given to the FDACS's presentation format. The governing criteria in this area is whether or not the presentation format correctly reflects the information collected by the system, not only in terms of the tables but in the written text as well. The effective presentation of the FDACS depends, in part, on the reader of the report.

- Design presentation format.
 - Take into account all tables, charts and figures.
 - Consult other reports, books or manuals dealing with fishing data for examples of clear and informative designs.
 - Include in the statistical results standard error measures.
 - Attach copies of questionnaires to the report.



SECTION III

RECOMMENDATIONS FOR IMPLEMENTING A FISHERY DATA COLLECTION SYSTEM

INTRODUCTION

Now that the DFW is instituting a formal fisheries data collection program it has the opportunity to develop a valuable tool for monitoring the fishing activity in Saipan. To assist the DFW in these efforts, this final section contains recommendations on the system's overall design as well as how to effectively implement the system. Generally speaking, these recommendations insure the development of a properly timed and flexible FDCS to meet the data collection needs of Saipan.

The data collection system must be built on sound conceptual and statistical survey principals. In this regard, special emphasis will be given to the recommendations involving the sampling design and expansion algorithm elements of the FDCS. In addition, each recommendation must fit within the constraints imposed by Saipan's existing fishing culture. Thus, the recommendations concerning the FDCS's structure will take into consideration present data collection methods and procedures. Recommendations related to each of the eight components to the FDCS are presented and discussed individually in this section.

OBJECTIVES OF A FISHERY DATA COLLECTION SYSTEM

Before proceeding with any additional data collection efforts, the DFW should formulate the objectives for the FDCS. These objectives should be clearly and concisely written and then reviewed by the appropriate DFW staff. Actually, the Division is faced with developing two sets of objectives: program and timing. Program objectives refer to those goals which identify the purposes and desired outcome of the data collection effort. The process for defining these objectives requires following the basic steps outlined in Section II. On the other hand, timing objectives specify when certain key events in the implementation process for the FDCS are to take place. For example, these timing objectives will denote when a given survey effort (e.g., an inshore survey) is to commence.

The DFW was asked to state its present and future objectives with regard to data collection activities. These objectives are summarized below:

- Biological information
 - Catch
 - Species composition
 - Species seasonality
 - Species location
 - Species weight/length relationship
- Fishing activity information
 - Fishing effort

- Fishing participation
- Fishing methods/gear
- Economic information
 - Cost
 - Earnings

Once the FDCC is fully operational, information concerning the above variables will be readily available. However, during the preliminary stages of the FDCC development, any attempt to measure all these variables will probably meet with little success.

In specifying the program and timing objectives, the DFW must realize the complexity associated with the FDCC. Therefore, the objectives set during the early stages of the FDCC should focus on the primary variables of the fishing activity. The overriding objective for a FDCC is to obtain reliable Island-wide total catch estimates. When the data collection activities are operating efficiently and a sufficient data base has been compiled, the more specialized variables can be measured. The initial objectives for the FDCC should be as follows:

- To obtain reliable Island-wide total harvest estimates as well as obtaining estimates of catch and effort with respect to fishing method, fishing areas, and species composition.

In conclusion, the universe under consideration for this data collection system is the fishing activity on the Island. The DFW should expect to spend five to 10 days of effort in specifying the system's objectives.

GENERAL DESIGN COMPONENTS FOR A FISHERY DATA COLLECTION SYSTEM

A review of the general design components (see Section II) uncovers a number of important factors that must be considered by the DFW prior to specifying a survey design. The following descriptions provide critical background information required when determining the feasibility of a proposed survey program.

Fishing Experience

While Saipan offers a unique fishing experience, it is possible to classify the Island's fishing activity into a fairly standard framework. First, Saipan's fishing activity, i.e., the survey universe, can be divided into two categories: inshore and offshore activity. Inshore activity is defined as fishing between the reef and the shoreline. This area includes the lagoon areas located on the leeward side of the Island. Hence, inshore activity can take place in a boat as well as on foot. On the other hand, offshore activity is defined as fishing which occurs beyond the reefs and, therefore, always requires the use of a boat.

Understanding the fishing experience enhances the likelihood of selecting the proper structure for the data collection system. There are three aspects to the fishing experience: the human, spatial and temporal. First, consider the human aspect of the fishing experience. Since it is the individual who participates in the fishing experience, the fishing experience must be measured in terms of the fisherman's activities. Information concerning the fisherman's catch and effort must be compiled as well as the overall fishing participation.

Human Factor. The human element is comprised of two groups: fishermen and non-fishermen. The fishermen and non-fishermen make up the population needed to determine the participation rates often used when assessing fishing activity. Therefore, in order to derive the necessary participation rates, information concerning the relative sizes of these two groups must be known. Unfortunately, this information is not available on Saipan. The closest information which could be used to extract participation rates comes from the National Recreational Fishing Survey conducted by NMFS. However, in talking with the FDW and reviewing the 1979 results, the consensus was reached that the participation information available from this recreational survey did not reflect the true levels of participation, and significantly underestimated the activity. Hence, the use of participation figures in evaluating fishing activity must be de-emphasized.

In Saipan, fishermen fish for one of three reasons: recreation, subsistence, or commerce. As Table 1 showed, the commercial fishery is primarily made up of part-time fishermen. For offshore fishermen, the principal methods are trolling, spearfishing, handline, and bottom fishing. While little, if any, data has been collected on inshore activity, the principal methods appear to be spearfishing, hook and line, and netting, i.e., cast, gill, surround. Also, within the reef area boats are able to troll and bottom fish, especially during seasonal runs. This presents the DFW with a problem of determining whether or not the above activity is inshore or offshore. According to the definition provided above, this activity must be classified as inshore fishing.

Spatial Factor. The second factor the DFW must consider is the spatial factor. Because Saipan is an island, this factor is well-defined. In principal, fishing activity could take place anywhere on the Island's coastline. Thus, the FDCS must define some means of determining exactly what level of fishing activity is occurring at a specific location. In the case of the offshore fishery, this will involve assessing the launching sites around the Island. Figure 3 identifies the five major launching sites for offshore fishing activity. Each site is located on the leeward side of the Island and is protected by the reef. Information provided by the DFW implies that little, if any, offshore boat launching occurs elsewhere on the Island.

Figure 3

MAJOR LAUNCHING SITES FOR OFFSHORE FISHING ACTIVITY



- 1 - Tanapag Village; Sand launch area
- 2 - Commercial Port and Sea Plane Ramp
- 3 - Memorial Park Boat Basin
- 4 - Garapan Fishing Basin
- 5 - Sugar Dock

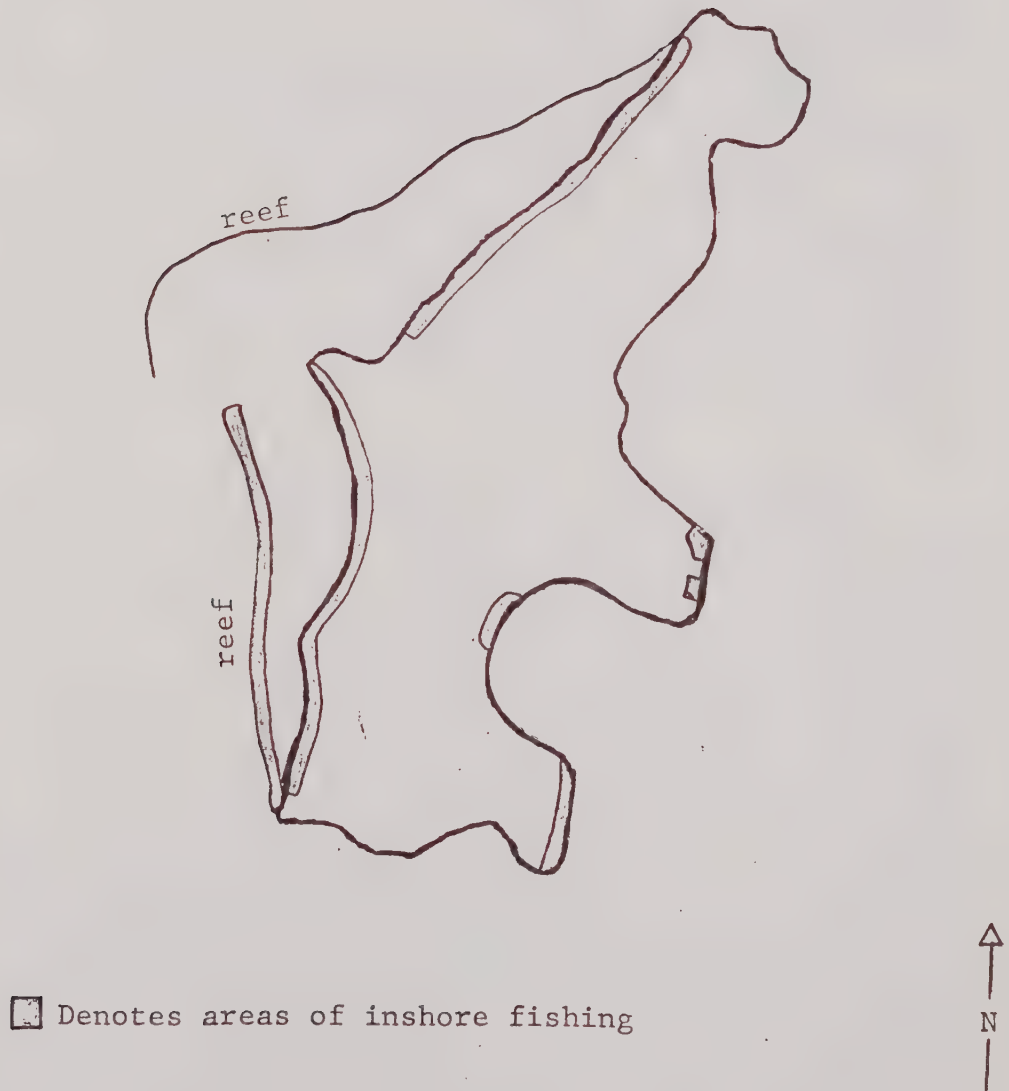
A similar approach must be taken for the inshore fishery. The entire shoreline of the Island must be reviewed and a method of estimating the fishing activity determined. Figure 4 indicates expected areas of inshore fishing activity. Again, the bulk of fishing effort is concentrated on the leeward side of the Island where the majority of the population is centered.

Depending on the selected sampling design, it is important to note that due to any number of reasons (i.e., budgetary, safety, etc.) it is possible, and in many instances desirable, to omit an area from consideration. However, without the use of a proxy measure, we must realize that omitting an area explicitly assumes zero fishing activity.

Temporal Factor. The final factor in the fishing experience is the temporal factor. The unit of measure of this factor is a day. Of essence here is the coverage aspect of the factor: the FDCS must take into account the entire unit of measure -- a 24-hour day. The simplest division for this factor is day fishing, i.e., dawn to dusk, and night fishing, i.e., dusk to dawn. The sampling design element of the FDCS must develop some means of estimating the fishing activity during these periods. For Saipan, the major temporal problem is the night fishing activity, especially for the inshore fishery. Both the inshore and offshore fisheries must be viewed from this temporal dimension in order to insure a complete FDCS.

Figure 4

EXPECTED AREAS OF INSHORE FISHING ACTIVITY



Surveying Factors.

Surveying factors represent the second design component. The first consideration in this area is the selection of what items are to be sampled and measured. For both the inshore and offshore fisheries, this unit is ultimately the fishermen. Basically, the FDPS is interested in the catch of the fishermen. Predominately, fishing activity in Saipan is collected at the market level, i.e., the retail outlet. The nature of the fishery and the habits of the fishermen are such that measuring fishing activity at the market level does not produce satisfactory results because the amount being bought and sold may not coincide with the amount caught. In addition, not all fishermen sell their catch. Therefore, the existing data may not necessarily reflect the total catch in the fishery. A review of past data by the DFW is recommended to assess the prevalence of this problem and ideally develop a measure of the non-purchased catch.

If sampling is required in the FDPS, the sampling units for the inshore fishery should be the fishermen, while for the offshore fishery, the sampling unit should be the fishing vessel. The procedure of sampling retail units may be of value when collecting economic data about the fishing activity. However, this type of sampling could introduce unnecessary bias if the purpose of the sampling is to obtain catch data. A good rule of thumb is: whenever a sampling scheme is being used, interview the individual doing the fishing if you want catch information.

Many possible means of surveying the fishing activity in Saipan exist, e.g., face-to-face interviews, voluntary logbooks, sampler observation, telephone survey, or mail survey. After comparing these methods with the objectives of the FDOS, three methods appear to satisfy the necessary requirements. These methods are face-to-face interviews, voluntary logbooks, and sampler observations. The face-to-face interviews will be directed towards the fishermen in the hopes of obtaining information not otherwise available, specifically catch and effort information. In the collection of participation information, sampler observation methods should be utilized whenever possible.

Of special interest in reviewing possible survey methods is the apparent feasibility of voluntary logbooks. The history of logbooks in collecting fishing data does not stand out. In fact, the system of surveying a fishery through the use of logbooks usually fails. However, Saipan may prove to be the exception. The proposed use of logbooks is for the offshore fishery. If the conditions identified in Section I are met, then logbooks should be successful.

Surveying Effort

Due to the newness of the data collection activities on Saipan, the information necessary to fully evaluate this component is unavailable. However, a few general remarks concerning the three factors influencing sampling effort, i.e., costs, variability, and tolerated error, can

be made. In the real world, budgetary considerations are the fundamental constraints on the sampling effort. Therefore, it is imperative that the DFW compute exact costing figures for existing and proposed sampling programs. These calculations should fully describe each cost factor and denote whether it is a variable or a fixed cost.

Until the DFW is able to compile catch data, the possibility of deriving variability estimates will be limited. Determining the variability of key variables is critical to assessing the required level of sampling. The greater the variability of a given variable, the greater will be the required sampling effort to obtain a reliable estimate. Caution should be employed if the purchase data is used to obtain a variance estimate of the catch. Undoubtedly, the type of fish sold may not have the same characteristics as those fish not sold, especially in terms of size variability.

Finally, the DFW must consider the level of error it is willing to tolerate in its estimates. The lower the tolerated error, the greater the required sampling effort. In order to evaluate the required sampling effort for a particular fishing activity or method, the DFW must compute a variance measure, then select a tolerated error value and a confidence level. The actual calculation would involve using classical sample size determination formulas.

In computing sample size values, the following formula can be used:

$$(1) \ n = \frac{N \cdot Z^2 \cdot (P(1-P))}{N \cdot e^2 + Z^2 (P(1-P))}$$

where

n = sample size estimate

N = population size estimate

Z = standard normal variate

P = proportion of fishermen using a given fishing gear

e = tolerated error

Equation (1) was selected because the sampling effort is directed towards the binomial decision of fishing or not or using a given gear compared with all other gears. Essentially, the sampling program measures the fishing activity on the Island. Therefore, if a program is to generate measures of fishing activity, adequate numbers of fishermen must be interviewed. Since the gear used by the fishermen is descriptive of the fishing activity, sampling effort is presented in a gear-specific manner. Hence, a binomial approximation underlines Equation (1). Thus, implicitly, the assumption is being made that fishing gears are independent. While exceptions to the assumption can be observed, their magnitude is insignificant as long as the fishing gear activity can be reported in an independent manner. For example, a fishing vessel on a single trip may troll and bottom fish. If the fisherman is able to separate the effort and catch related to these methods, the sampler can report these as two separate trips.

In computing the sample sizes, it is important to note how the tolerated error (e) value is calculated. Tolerated error can be viewed in either an absolute or relative sense. In its absolute sense, the value of the error term is a number independent, for the case at hand, of the fishing gear participation rate.* In other words, an error value of 10 percent will generate estimates within 10 units of the participation rate. Therefore, if the participation rate equals 20 percent, the acceptable range becomes 10 to 30 percent. Tolerated error in its relative sense implies the error value is dependent upon the participation rate consideration. Hence, an error value of 10 percent will generate estimates within .1 times P (participation rate). Following the above example, with a 20 percent rate, the acceptable range in this case becomes 18 to 22. For the purposes of Equation (1), the tolerated error term is calculated in its relative sense.

THE SAMPLING DESIGN

After assessing the body of information concerning Saipan's fishing activity, the following general sampling design is recommended. This proposed design accounts for the many unique features of the Island's fisheries plus

*See "A Recommended Approach to the Collection of Marine Recreational Finfishing and Shellfishing Data on the Pacific Coast," Contract No.6-35339, National Marine Fisheries Service, Data Management and Statistics Division, Washington, DC, August 1977, pp. 15-18.

draws from the current data collection efforts of the DFW. Basically, the design is comprised of two major independent elements: inshore and offshore activity. Each element will be discussed in detail below. Because the DFW's primary efforts to date have been directed at the offshore fishery, it will be presented first.

Offshore Fishery Survey

The proposed offshore survey is a census and not a sample type of survey. The difference between a census and a sample survey is critical, especially in developing the FDOS. A census survey's goal is to obtain information on every member of a population, while a sample survey collects information on a subset of the population.

Through the use of boat licensing records, the DFW is able to identify all boat owners. In addition, the primary use of the boat is available along with other related information. This boat list comprises the population of offshore fishermen. Members of this population are classified as full-time commercial, part-time commercial, recreational, or non-fishing.

A logbook is distributed to each fisherman. Due to the significant amount of public relations work, training, and follow-up which must go into properly distributing the logbook, the books should be time-released. Instead of being handed out indiscriminately, the logbooks should be given to certain subgroups. Once a subgroup is familiar with the logbooks, another subgroup should be added.

Three subgroup categories readily come to mind: full-time commercial, part-time commercial, and recreational.

The fishermen are directed to complete a logbook entry at the conclusion of each fishing trip. If each offshore fisherman recorded the desired fishing information after each trip, the resulting logbook information would indicate the total catch, effort, and participation of the offshore fishery. No expansion method would be required for the offshore activity.

However, the DFW must be prepared for the likely event that the 100 percent response rate does not occur. A number of possible difficulties exist with respect to the logbook program; each would require a different response. A few examples will be discussed here. For example, for the most part, the logbook operates properly except that each logbook has information missing or the fishermen fail to account for a trip. As long as these occurrences do not make up a significant portion of the logbook's entries, (e.g., greater than 10 percent), the proper adjustments can be made during the expansion procedures. For example, if a week were omitted from a logbook, either the fisherman's average catch and trips could be used as a proxy for the missing week, or the activities of a comparable fisherman could be used. In either case, it is important that a proxy measure be developed for all missing information.

Should a particular subgroup fail to maintain logbook information at a desired level, two options exist. One option would be to drop the subgroup from the program and introduce a new sample survey for that subgroup. A second option is to alter the logbook program from a census to a sample program. Essentially, this would require the DFW to devise a sampling strategy for obtaining the logbook information. For example, if the part-time commercial fishermen are no longer completing the desired information on a regular base, each fisherman could be contacted and asked to participate in the program intermittently. Thus, a fisherman may be asked to fill out a logbook on every fourth trip, or for all trips during the second week of each month. Under this scheme, the logbook data could be compiled and an expansion method developed to generate the necessary estimates. Obviously, many new problems will arise, e.g., monitoring the fisherman to make sure logs are filled out at proper times. These problems must be addressed and resolved.

Finally, if the entire logbook program collapses, then a sample survey must be introduced. This new sample survey would collect data on an intermittent basis. With the vast majority of the boat activity occurring from the five launch areas identified in Figure 3 (Section 1), a surveying program involving sampling individual boats returning from fishing trips could be devised. An example of such a program is outlined in the report "A Fishery Data Collection System: Guam," which can be made readily available to DFW. Also, the

proposed inshore survey for Saipan could be adopted. Undoubtedly, modifications in the program would have to be made to fit the Saipan fishing experience.

In conclusion, if the logbook program is properly implemented and the DFW maintains continuous monitoring of the fishermen's activities, the program should be successful. Actions by the DFW currently underway are an important first step in this direction. Information from the logbook program would cover all aspects of the fishing activity in Saipan (e.g., night fishing), with the possible exception of illegal fishing. Assistance in obtaining information on illegal fishing could be available by asking the fishermen to detail on the proper form any such activity they witness.

Inshore Fishing Survey

The collection of inshore fishing data is a new experience for the DFW. Therefore, the division should give special consideration to this survey, especially during the planning stages. The following description of the inshore survey can provide insight into the development of an offshore sample survey if that should become necessary.

To insure the completeness of the inshore sampling design, a single survey procedure and two qualitative inference methods are proposed. The survey procedure is

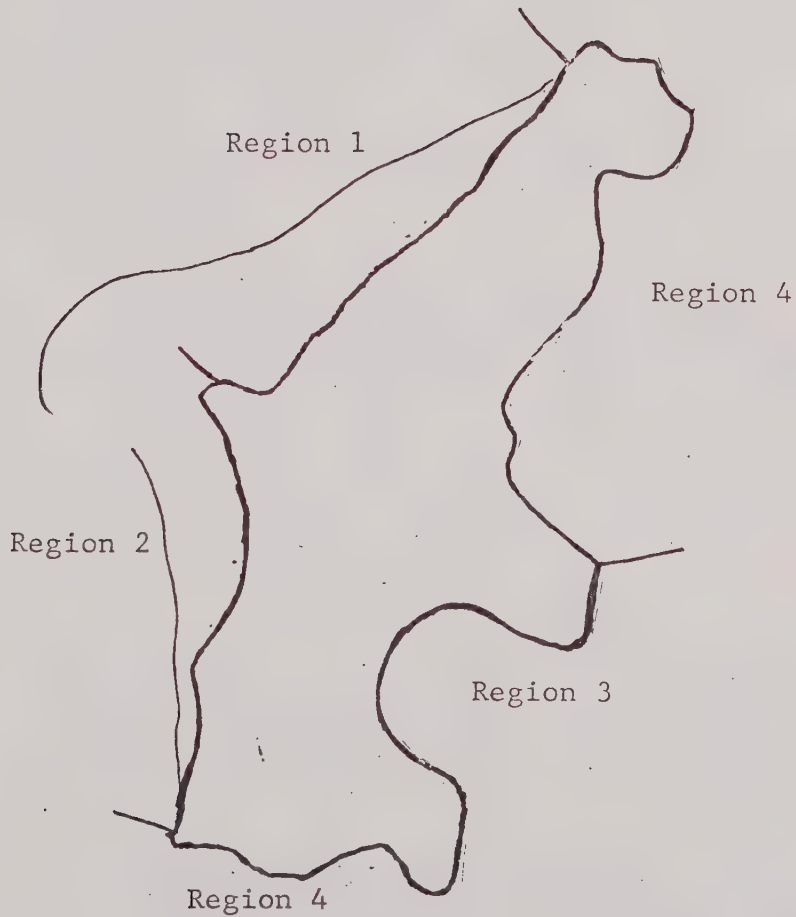
a catch/effort sample survey. The two qualitative methods are aimed at quantifying night and illegal fishing activity.

Statistical Survey Method

This survey method is directed at obtaining data on daytime fishing activity. In addition, this method is designed in such a manner as to insure that the proper expansions can be made.

Geographical Division of Coastline. Using the expected areas of inshore fishing (refer to Figure 4 as a guide), the Island can be divided into four regions (see Figure 5). Regions 1-3 define the area where the expected fishing activities occur, while little if any effort should be observed in Region 4. To further assist in the reporting of the fishing location of the fishermen, the DFW should devise a finer breakdown of the Island's geographical areas. Such a well-defined mapping of the Island will enable the sampler to assign the location of each sighted fisherman to a relatively small area.

Figure 5
FOUR INSHORE FISHING REGIONS



Variability of Fishing Activity Between WE/H and WD.

If, in fact, significantly different rates of fishing exist between WE/H and WD, it must be reflected in the proposed survey design. In order to properly account for the difference in variability, sampling effort must be stratified by WE/H and WD. Should the DFW desire separate estimates for WE/H and WD, additional sampling effort will be required. After collecting a sufficient amount of data, the DFW should closely analyze the WE/H and WD information to determine the most beneficial course of action.

Impact of Weather on Fishing Activity. Changes in weather influence fishing participation for both inshore and offshore activity. These factors must be incorporated into the survey design and results (see Malvestuto, et al, Trans Am Fish Soc. 1979). Along with the fishing information collected, DFW should maintain a record of weather conditions. Once collected, DFW should study this data and correlate the relationship between climatic variables with fishing activity. If necessary, a separate study should be undertaken to develop these relationships. Once the desired relationships have been compiled and statistically supported, they can be used. As needed, periodic updates of coefficients can be undertaken.

General Design of Surveys. The foundation of the proposed sampling designs is based on a paper by Malvestuto, et al, entitled "An Evaluation of the Roving Creel Survey

with Nonuniform Probability Sampling."* In this paper, the authors detail an application of the roving creel survey with non-uniform probability sampling. The basic procedures outlined in this paper can be adapted to sampling activity in Saipan. Essentially, the sampling scheme generates an unbiased sampling and estimation of fishing success. Fishing success is defined as the weight of fish caught per fisherman hour or catch per unit effort (CPE).

The basic features of this proposed approach can be summarized as follows:

1. The entire period for which the fishery is to be surveyed is divided into time blocks. Ideally, the amount of fishing expected to take place within these blocks should be similar. DFW should review past fishing data and determine the most appropriate division of these time blocks. This review must take into account various seasonal factors, i.e., species, climate, etc. Currently, these time blocks are one month in duration. For the purposes of this study, the one month figure will be used.
2. Each time block is divided into sampling units. A sampling unit defines the time periods during which sampling will take place. In addition, all of the fishing time within a block is contained within the sampling units and the units do not overlap.
3. Assigned to each sampling unit is a sampling probability proportional to the amount of fishing expected for the unit. The sum of probabilities assigned to the sampling units within any given block equals 1.0.
4. Sampling units are randomly chosen within each block on the basis of the assigned sampling probabilities. Therefore, there exists a proportional relationship between the probability

*See "An Evaluation of the Roving Creel Survey with Non-uniform Probability Sampling." by Stephen P. Malvestuto, William D. Davies, William L. Shelton; Transcript American Fishery Society 107 (2):255-262, 1979.

that sampling will actually be done during any given sampling unit, and the amount of fishing occurring during the unit.

5. Sampling activity is comprised of two components: fishermen counts and catch/effort interviews. Multiple gear trips must be counted as a separate trip for each gear used. This is true for both the offshore and inshore fisheries. The sampler will have to allocate certain responses to each gear, e.g., fishing effort.

Inshore Sample Survey. As the name implies, the catch/effort survey is a sample survey. Its purpose is to collect information concerning catch and effort activity by the inshore fishermen. Of the major inshore fishing methods, spearfishing and hand line are considered by the DFW to be the most prevalent. Most of the inshore fishing on the Island is done in the lagoon area.

The proposed inshore survey follows a stratified area sampling design. The survey is directed towards obtaining daytime catch information. Sampling times are to be varied to insure complete coverage of the day period. Area sampling is a term commonly used when the sampling activity is based on geographical areas. The survey is designed to intercept the fishermen along the coastline or within the lagoon. The sampling program is divided between coastline and lagoon intercepts. The reason for this division is that lagoon intercepts will require the use of a boat. To survey the entire Island will require two days -- one day for each type of intercept.

Ideally, sampling effort should be allocated to the four regions according to historical catch data; however, such data does not exist. Instead, the sampling effort between the regions will be allocated according to the distribution of households among the regions. The underlying assumption here is that coastline fishermen are more likely to fish near their residences. Table 3 presents the proportion of catch from each region.

Table 3
PROPORTION OF
CATCH BY REGION

<u>Region</u>	<u>Proportion of Catch by Region</u>
1	.20
2	.69
3	.11
4	-0-

Source: CIC Research, Inc.

These factors are guidelines for the sampler in allocating his/her time during a sample day. Thus, 20 percent of the sampler's time should be spent in Region 1 with 69, 11, and 0 percent spent in Regions 2, 3 and 4 respectively. Most of the sampler's effort is allocated to Region 2. The DFW is encouraged to develop allocation factors which may more closely reflect inshore activity.

The proposed inshore survey follows the general design previously presented, but also introduces a stratified area sampling design. Because the size of the Island's surveyable regions is so large, it is necessary to divide the Island into more manageable groups. The inshore survey is a continuous program; hence, one-month time blocks are proposed.

The survey is directed towards obtaining daytime catch information. Each time block is divided into three sampling units: A.M., Noon, P.M. Basically, these units encompass the following time intervals:

A.M. - Dawn until 1000 hrs.

Noon - 1000 hrs. until 1400 hrs.

P.M. - 1400 hrs. until dusk

The above sampling units define the temporal component of the sampling scheme.

The area sampling element must be addressed. Area sampling is a term commonly used when the sampling activity is based on geographical areas. The survey is designed to intercept the fishermen along the coastline. Using the geographical divisions developed, the following stratification system has been developed.

The first level of stratification is the four survey regions. A review of Table 3 shows that 20 percent of the sampled catch is expected to occur in Region 1 with 69 percent, 11 percent and 0 percent occurring in Region 2, 3 and 4 respectively. For the inshore survey, sampling

effort is allocated by the proportional size of the first particular area strata and then by the time period (sampling unit). Therefore, 20 percent of the overall sampling effort is to be allocated to Region 1 with Region 2 and 3 receiving 69 and 11 percent, respectively. Then, for example, the 20 percent allocated to Region 1 will be disaggregated proportionally to the three sampling unit time periods. DFW should refine these probability values by reviewing past inshore activity. For a given region, interview responses are categorized into one of the three sampling units according to the time of the interview. From these groupings probability values are derived.

A six-day per month sampling level should be adequate during the initial stages of the program. Six days of effort translates into 12 sampling units to be worked each month. The above conversion assumes that two sampling units can be surveyed in one day of effort. Thus, during each time block, the possibility exists that all regions and time periods (sampling units) will be sampled.

However, if the sampling program stratifies the effort by WE/H and WD, the above sampling effort cannot sample all regions and time periods in a time block of one month. A total of nine survey days would be required (that represents 18 sampling units). This coverage factor is not essential to the overall sampling program when taken in the context of a year. In the case of missing cells for a given time block, proxy values from past data could be used.

In reality, the set of sampling units becomes a particular region and a given time period. The set of sampling units contains nine basic elements if WE/H and WD are aggregated together, and 18 elements if WE/H and WD are separated. Assigned to each element is a probability value comprised of the product of the sample probabilities for each region and time period. Once these values are derived, the sample for a given time block can be drawn.

On a given sampling day, one sampling unit (defined as above) is surveyed by a sampler. Primarily, the sampler's activities entail making fishermen counts and catch/effort interviews. The DFW's must develop inshore catch/effort and participation questionnaires which address all the data information needs of this survey.

Once the sampler arrives at the desired region, he/she should make a count of fishing activity throughout the entire region. During this participation assessment effort, factors concerning location, gear, time, and weather conditions should be recorded. After the sampler has completed this portion of his/her activities, then catch/effort interviews are to be taken. Since the sampler has an idea of the current status of the fishing activity within the region, the sampler should be able to more efficiently interview the fishermen. By reviewing the participation results, the sampler will be able to allocate his/her time and interview a representative sample of fishing activity by gear.

To survey the lagoon will require the use of a boat. The mobility of a boat provides the fishermen with a greater range of fishing activity; therefore, the sampler should spend part of the day patrolling the entire lagoon area. The nature of the fishing activity in the lagoon is not conducive to sampling efforts. Therefore, the sampler must devise a method for obtaining the data without unduly bothering the fishermen. For example, a spearfisherman who swims from the coastline may provide the desired information while the sampler takes the fisherman back to shore. In any case, the collection of catch/effort data from the lagoon survey is going to be difficult.

As additional information about the inshore fishery becomes available, more specific allocation factors can be developed corresponding to areas within each region. Again, these sector allocation factors should not be considered as hard and fast rules governing the sampler's decisions. Changes in hot fishing spots during the sample period will require the sampler to alter his/her decisions on time allocation. The key to this survey is obtaining good quality catch and effort data.

As information is collected and analyzed, the DFW may discover that catch and effort figures do not vary within certain areas. If this is the case, the DFW should condense the sampling areas to increase the efficiency with which the

data is collected. In addition, the DFW must study how average catch figures differ between areas of WE/H and WD periods.

To determine the sampling effort required and to adequately measure average catch, disaggregated inshore catch data should be reviewed. Unfortunately, this catch data is not currently available. A possible proxy for this data may be the inshore catch values from Guam, especially for the Merizo region. The Department of Aquatic and Wildlife Resources in Guam is planning a survey effort specifically geared to the Merizo region. The data from this survey would assist the DFW in computing total sampling effort. Minimum sampling levels are guessed to be between three and four days per month for a tolerated error of less than, or equal to, 25 percent.

Major Steps Required When Implementing Sampling Design:

1) Determine duration of time blocks: 1 month.
The survey period of one year has been divided into 12 time blocks.

2) Divide time blocks into sampling units:

Inshore Survey

Sampling units: A.M., Noon, P.M.

3) Compute and assign sampling probabilities (P) to each sampling unit.

Inshore Survey

A total of 18 basic probabilities need to be calculated:

$P_{AM, Region 1}^{WE/H}$ = For WE/H, the probability of a fisherman fishing during the A.M. hours in Region 1.

$P_{Noon, Region 1}^{WE/H}$ = For WE/H, the probability of a fisherman fishing during the noon hours in Region 1.

$P_{PM, Region 1}^{WE/H}$ = For WE/H, the probability of a fisherman fishing during the P.M. hours in Region 1.

Similar probabilities are calculated for Regions 2 and 3, i.e.,

$P_{Noon, Region 2}^{WE/H}$

$P_{PM, Region 2}^{WE/H}$

$P_{AM, Region 2}^{WE/H}$

$P_{Noon, Region 3}^{WE/H}$

$P_{PM, Region 3}^{WE/H}$

$P_{AM, Region 3}^{WE/H}$

In addition, another nine probabilities are computed for the WD period, e.g., $P_{AM, Region 1}^{WD}$, ...

To compute these possibilities, the survey data is categorized according to each of the nine probability descriptions for either the WE/H or WD group. For example:

$P_{AM, Region 1}^{WE/H}$ = $\frac{\text{the number of fishermen fishing in Region 1 in the A.M. hours on a WE/H}}{\text{the total number of fishermen fishing on a WE/H}}$

If DAWR is unable to divide the survey data in the manner above, the similar probabilities of $P_{AM}^{WE/H}$ and $P_{Region\ 1}^{WE/H}$ can be computed with the product of these values equaling the desired joint probability.

4) Randomly Select Sampling Units.

Inshore Survey

The selection of sampling units for the inshore survey follows the same format, only the procedure is a bit more complicated. A total of 12 sampling units are to be sampled each month, six for WE/H and six for WD. Using February as an example, a total of 54 sampling units are possible for WD and 30 sampling units for WE/H. In the case of WE/H for a given region, 10 sampling units are A.M., 10 units are Noon and 10 units are P.M. The six WE/H sampling units to be surveyed are determined according to the probabilities computed above. For example, if $P_{AM, Region\ 1}^{WE/H} = 15$ percent, then 1 ($.15 \times 6$) of the sampling units to be surveyed falls in the A.M., Region 1 group. The particular days to be surveyed are then randomly selected, a total of six sampling days are selected for WE/H period.

5) Conduct Survey

Qualitative Inference Methods

The previous sampling designs together provide a method for generating statistically based fishing estimates. In order to complete the fishing picture in Saipan, two additional fishing activities must be considered: nighttime and illegal fishing. Neither of these activities can be adequately sampled using a survey method. Instead, some other means must be employed to furnish an estimate of these two types of fishing activity which are basically limited to the inshore fishery; each activity will be discussed separately.

(1) Nighttime Fishing. According to the DFW, nighttime fishing activity is prevalent enough to warrant numerical estimates. Basically, the nighttime estimate is a proportional figure tied to the level of daytime fishing. For example, if daytime catch is estimated at 100kg and the proportional nighttime rate is 25 percent, then the estimated catch is 25kg.

At issue is identifying and selecting those procedures which will provide information concerning the relative size of the night proportion. A number of possibilities exist for obtaining the desired information. First, attached to the catch/

effort survey could be a question concerning night fishing activity. The scope of the questions could include not only the night activities of the intercept fishermen, but also those individuals known by the fishermen. Additional questions involving fishing method, location, size of catch, etc., could be asked.

While the DFW does not currently employ conservation officers, the Division is expected to in the near future. Therefore another approach would be for the conservation officers (as part of their job description) to keep a tally of night fishing during their patrols. The use of conservation officers in this manner could prove to be most valuable. Also short-term surveys could be conducted by telephone or mail concerning night fishing. The list of subjective methods, e.g., asking "knowledgeable" individuals, is endless. The most productive method, however, appears to be utilizing the conservation officers or attaching night fishing questions to the existing surveys.

(2) Illegal Fishing. According to the DFW, Saipan is faced with a fairly significant illegal fishing problem, which, over the long run, could have a lasting destructive impact upon the inshore fishery. From a data collection viewpoint, however, the illegal fishing must be numerically estimated. The same proportional method used for night fishing is to be employed in developing an illegal fishing figure. The nature of il-

legal fishing activity prohibits the use of traditional survey methods. Instead, qualitative methods must be undertaken to determine the desired proportional rate.

One possibility for assessing the illegal fishing activity would be to inform the populace through a public relations blitz of the consequences of this activity. The public's assistance should be solicited in reporting illegal activity to DFW personnel. All reports would be compiled to determine a measure of the activity. To assist in calculating the catch associated with the illegal fishing, the DFW could estimate possible kill rates for particular illegal fishing activity. These estimates would take into account locations, species prevalence, fishing method, etc. These figures would be used in assessing the illegal rate.

Another alternative would be to ask fishermen about their knowledge of illegal fishing activity. The subject of illegal fishing is very sensitive; therefore, the sampler must take the necessary precautions to assure the fisherman of the desired information's purpose and confidentiality. Also, questions on illegal fishing activities could be added to the catch/effort surveys. The problem of illegal fishing cannot be ignored by not incorporating the activity in the Island's catch estimates. Instead, the DFW must experiment with different procedures for measuring the Island's illegal fishing activity.

Timing of Surveys

The proposed sampling design is comprised of two primary survey efforts, one generally for the offshore and one for the inshore fishery. The first effort of the DFW should be directed to the offshore logbook program; it will probably take a year to make the program fully operational. Once the offshore program is operating correctly, the inshore program should be implemented, first the participation census, and then the catch/effort survey. Should the logbook program fail, the inshore program format can be adapted to the offshore fishery.

THE SAMPLING ACTIVITY

The scope of this project does not include a detailed discussion of the necessary sampling activities. However, a few recommendations concerning these activities are presented below.

Offshore Fishery Survey

For the logbook program to work, the DFW must fully train each fisherman to properly fill out a log sheet. This training includes explaining how the log sheet is to be filled out on a question-by-question basis. Examples of completed log sheets would help the fisherman visualize how the sheets are to be completed. Also, the fisherman must understand the need to have a sheet completed for each trip. Once the fisherman is trained, the DFW must monitor the activities of each fisherman, especially during the early stages of the program. The DFW

should devise a regular schedule for meeting with the fishermen and reviewing his logbook.

Inshore Fishing Survey

Prior to conducting the actual survey operation, a number of preparatory steps must be undertaken. First, the sampling design must be transformed into a series of detailed and well-defined sampling procedures. For example, the driving route for the participation census must be designed, tested, and timed.

The DFW must design an inshore participation and catch/effort questionnaire. In constructing this instrument, the DFW should carefully review existing questionnaires used elsewhere (the closest being Guam). In addition, the DFW must develop the corresponding survey documents that are required to assist in the data collection effort. Finally, the samplers must be thoroughly trained in the techniques of collecting fishery information.

PROCESSING THE SYSTEM'S DATA BASE

The key to processing the FDC's data base is knowing where and how to find each survey instrument at any time. Thus, when mistakes are made in creating the data base, they can be corrected. During the processing procedure, each questionnaire must be checked for completeness, consistency, and proper coding. Finally data from all the questionnaires should be keypunched into a computer file as soon as possible.

EXPANSION ALGORITHMS AND THEIR RELIABILITY

The expansion equation is the device which transforms the survey results into the desired Island-wide estimates. The primary estimate for the FDCS is the total Island catch. The catch expansion equation can be viewed in two ways: in terms of the area or type of fishing activity involved, or the individual variables which make up the equation. With regard to fishing activity, the equation is simply the sum of the estimated offshore and inshore catch. Depending on the success of the offshore logbook program, the offshore catch figures will either represent the actual total offshore catch or an estimate. On the other hand, the inshore catch figure will always be an estimate.

However, survey results provide information only for the sampled inshore fishing activity. In order to ultimately develop the desired Island-wide estimates, a series of equations are used to transform the survey data into its final form. The expansion methods can be viewed in terms of three general steps:

- Computations for daily catch estimates
- Computations for mean daily catch
- Computations for mean daily catch per month

The sample data is expanded as follows:

Computations for Daily Catch Estimates

- (1) First, calculate an estimate of total sampling period effort

$$e = n \times \bar{h}$$

where e = total effort expended during sampling period

n = number of fishermen (vessels) counted

$\bar{h}$ = average number of hours fished

Inshore and offshore total sampling period effort are calculated separately. Since the inshore survey primarily deals with incomplete trips, $\bar{h}$ equals actual hours fished plus the additional expected hours to be fished. Equation (1) can be disaggregated by gear (or other variables) if desired. For example, Equation (1) becomes

$$(1)' \quad e_i = n_i \times \bar{h}_i$$

where, i = gear being used

therefore,

$$(1)'' \quad e = \sum_i e_i$$

- (2) Second, determine the estimate of total day effort

$$E = e / p_1 p_2$$

where,

E = total island effort for fishing day

p_1 = proportion of fishing activity occurring in a given sampling period

p_2 = Proportion of fishing activity occurring in a given region

Obviously, the key to Equation(2) is properly specifying P_1 and P_2 for both inshore and offshore activity. The disaggregation of Equation (2) by gear yeilds the following

$$(2)' \quad E_i = C_i/p_1p_2$$

if possible, the p_1 and p_2 variables should be gear specific therefore,

$$(2)'' \quad E = \sum E_i$$

- (3) Next, calculate the estimate of catch per unit of effort

$$CPE = \frac{B}{P}$$

where,

CPE = catch per unit of effort

B = total recorded weight of fish sampled

P = total measured pressure recorded during sampling, e.g., total number of actual hours fished.

The data for Equation (3) is supplied solely from the survey results. Equation (3) can be disaggregated by gear as follows:

$$(3)' \quad CPE_i = \frac{B_i}{P_i}$$

therefore,

$$(3)'' \quad CPE = \sum w_i CPE_i$$

where,

$$w_i = \frac{P_i}{\sum P_i} ; \sum P_i = P$$

- (4) The final calculation of this category is to estimate the total day catch

$$C = CPE \times E$$

where, C = total day catch.

Disaggregated by gear Equation (4) becomes

$$(4)' \quad C_i = CPE_i \times E_i$$

therefore,

$$(4)'' \quad C = \sum C_i$$

Computations for Mean Daily Catch

The mean daily catch is determined for each stratum. For the case at hand, the allocation between WE/H and WD, represent separate strata.

- (5) The mean daily catch for each stratum is defined as

$$\bar{C}_{WD} = \sum_{\ell=1}^{n_{WD}} C_{WD,\ell} / n_{WD} ; \quad \bar{C}_{WE/H} = \sum_{\ell=1}^{n_{WE/H}} C_{WE/H,\ell} / n_{WE/H}$$

where,

$$\bar{C}_{WD}, \bar{C}_{WE/H} = \text{mean daily catch}$$

$$C_{WD,\ell}, C_{WE/H,\ell} = \text{estimated total day catch for } \ell\text{th day}$$

$$n_{WD}, n_{WE/H} = \text{number of days sampled}$$

Disaggregated by gear Equation (5) becomes

$$(5)' \quad \bar{C}_i = \sum_j C_{ij} / n_i$$

where, $\bar{C}_i$ = mean daily catch for i^{th} gear

C_{ij} = estimated total day catch for i^{th} gear
on j^{th} day

n_i = number of days sampled for i^{th} gear

therefore,

$$(5)'' \quad \bar{C}_{\text{WE/H}} \text{ or } \bar{C}_{\text{WD}} = \sum g_i \bar{C}_i$$

where,

$$g_i = \frac{n_i}{N}$$

N = total number of days sampled

$$\text{Note: } \bar{C}_{\text{WD},i} = g_i \bar{C}_i$$

The variance associated with the mean daily catch is defined as follows:

$$(6) \quad \text{Var} (\bar{C}_k) = \frac{\sum_{\ell=1}^{n_k} C_{k\ell}^2 - \left(\sum_{\ell=1}^{n_k} C_{k\ell} \right)^2 / n_k}{n_k - 1}$$

where,

k = the strata, i.e., WE/H, WD

n_k = the number of days sampled with the k^{th}
stratum, i.e., n_{WD} ; $n_{\text{WE/H}}$

Computations for Mean Daily Catch Per month

To calculate the mean daily catch per month, the following equation is used:

$$(7) \quad \bar{C}_d = \frac{N_{\text{WD}}}{N} \bar{C}_{\text{WD}} + \frac{N_{\text{WE/H}}}{N} \bar{C}_{\text{WE/H}}$$

where,

$\bar{C}_d$ = Mean daily catch per month

N_{WD} = Total number of WD in month

$N_{WE/H}$ = Total number of WE/H in month

N = Total number of days within month

Disaggregated by gear, Equation (7) becomes

$$(7)' \quad \bar{C}_{di} = \frac{N_{WD}}{N} \bar{C}_{WD,i} + \frac{N_{WE/H}}{N} \bar{C}_{WE/H,i}$$

therefore,

$$(7)'' \quad \bar{C}_d = \sum_i \bar{C}_{di}$$

The variance for the mean daily catch per month is defined as:

$$(8) \text{ var. } (\bar{C}_d) = \sum_k W_k^2 \text{ var } (\bar{C}_k) / n_k - \sum_k W_k \text{ var } (\bar{C}_k) / N$$

where, W_k = the stratum weight (N_k/N)

The expansion system can account for the climatic impact on fishing activity in one of two ways. First, a sampling day could be used regardless of climate condition. Thus, changes in activity would already be accounted for in the survey results. Second, sampling could take place during "normal" climatic conditions only. DFW should consider the option of conducting a study on how climate conditions affect fishing activity for both inshore and offshore activity.

The final steps in the expansion involve the following three steps:

- (9) The total harvest for the month ($\hat{C}$) equals $N \times \bar{C}_d$
- (10) The standard error of the total harvest (s) equals $N (\sqrt{\text{var} (\bar{C}_d)})$
- (11) The 90 percent confidence limits for total harvest are $\hat{C} \pm t_{df} s$. The degrees of freedom (df) which determine the t value can be approximated using the number midway between the smallest value of $n_k - 1$ and $\sum n_k$.

It should be noted that the same sequence of calculations can be followed to estimate total effort or CPE by making the appropriate substitutions.

The above methods furnish catch estimates for inshore activity. In order to derive a total Island-wide estimate, offshore activity night fishing and illegal fishing values must be factored in. Basically, night and illegal fishing variables enter as scalars in the computation procedures for the catch estimate objective. Should the offshore program require sampling, a similar sampling scheme to the inshore can be developed easily.

QUALITY ASSESSMENT METHODS

The FDCS calls for a number of data handling phases, e.g., keypunching, and with each handling the chance of error increases. Therefore, the quality assurance techniques must be geared to evaluating if this additional error is significant and, if so, to correct the problem. The DFW must care-

fully review each step in the data collection and processing sequence and identify those areas where special quality assurance procedures should be implemented. For example, as the data is entered into the computer, an error program could be used which checks the range of each variable as it is entered and rejects any answer which does not fall into the acceptable range.

PRESENTATIONS OF THE FISHERY DATA COLLECTION SYSTEM

In conjunction with developing the FDACS's sampling design, the DFW should construct the presentation format for the FDACS. By undertaking both of these activities during the same period of time, the DFW can be assured of the compatibility between these two components. The results of these efforts will be the presentation of an FDACS in a clear and concise manner.

